INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES

Vol 16, Issue 4, (2026) E-ISSN: 2222-6990

Dynamic Tankering Model for Minimizing Fuel Costs in Aviation Operations

Arif Selim Eren[1], Mehmet Ali Orhan[2], Zafer Duran[3]

[1]Associate Professor, Ph.D., Kahramanmaraş Sütçü İmam University, Faculty of Economics and Administrative Sciences, [2]Lecturer, Ph.D., Kahramanmaraş Sütçü İmam University, Vocational School of Social Sciences, [3]Faculty Member, Ph.D., Alanya Alaaddin Keykubat University, Gazipaşa Mustafa Rahmi Büyükballi Vocational School

DOI Link: http://dx.doi.org/10.6007/IJARBSS/v16-i4/27884

Published Date: 19 April 2026

Abstract

This study develops a dynamic tankering model aimed at minimizing fuel costs in aviation operations and evaluates its economic effects under different operational scenarios. A quantitative research approach was adopted, considering fuel price differences between airports and the additional fuel consumption caused by carrying extra fuel. The model is based on the fuel penalty approach and a break-even condition that determines when tankering becomes economically rational. The proposed algorithm was implemented as an Excel-based decision support tool. Total fuel cost, additional consumption, and net cost advantages were calculated by comparing scenarios with and without tankering. The results indicate that tankering can reduce total fuel costs when the fuel price difference between airports exceeds a specific threshold. However, carrying additional fuel increases aircraft weight, resulting in extra fuel consumption and operational constraints that may limit economic benefits. Sensitivity analysis shows that the model is particularly sensitive to fuel price differences, the additional fuel consumption coefficient, and flight distance. The findings suggest that tankering decisions should consider not only fuel price advantages but also flight distance, aircraft performance, operational limitations, and sustainability objectives. The proposed model provides a practical analytical framework for supporting fuel procurement and flight planning decisions in airline operations.

Keywords: Aviation, Tankering, Cost Optimization, Fuel Management, Airline Operations

Introduction

As the global economy continues to evolve, airlines have increasingly turned toward cost management processes that utilize data and analysis in order to operate efficiently in the face of intense competition. Decision-making tools that are driven by data are being utilized more frequently as airlines implement methods to manage costs (Bhattacharyya & Salim, 2015; Hassan et al., 2021). Also, airlines are now using cost accounting methods to assist with flight planning due to the fact that fuel costs represent such a significant portion of total operating expenses (Baker et al., 2002; Smith et al., 2004). As a result of this trend, airlines are utilizing activity-based costing in their operational decision-making by using multiple variables including route, fleet type, load factor, and airport charge to provide a basis for understanding cost behavior (Guerreiro et al., 2013). Cost management in international applications has been recognized to be, and to serve as, an accounting-based control measure; however, it has also been recognised as a management tool that aids in providing strategic competitive advantage (Singh et al., 2019).

It is observed that global fluctuations in fuel prices and carbon emission regulations have a decisive impact on the cost structure, and therefore, operational optimisation models aimed at reducing fuel consumption are widely used (Deo et al., 2020; Shen et al., 2024). In addition, it is stated that tankering practices in flight operations are evaluated in conjunction with route optimisation and fleet planning decisions for the purpose of cost minimisation (Kang & Hansen, 2018; Tabernier et al., 2021). With the increasing use of big data analytics and decision support systems in airline operations, cost estimation models have become more dynamic, and operational planning processes are conducted based on real-time data flows (Hubert et al., 2015). As a result of these developments, it is assessed that the cost accounting approach in the aviation sector has moved away from static budget control towards a holistic cost management approach that also encompasses risk management, energy efficiency, and sustainability dimensions (Hassan et al., 2021).

Consequently, it is known that fuel price differences between airports have a significant impact on operational costs within the sector. It is stated that, due to the high proportion of fuel costs within total operating expenses for airlines, the price levels at different airports are considered a decisive factor in flight planning decisions (Nangia, 2006; Kang & Hansen, 2018). Fuel prices in international flight networks vary considerably depending on various factors such as tax policies, local competitive conditions, supply chain structure, and regional energy costs (Smith & Kunz, 2007). As a result, it is noted that airlines have developed strategic approaches to procure fuel from airports with lower prices and that these price differences are taken into account in operational planning processes (Mao & Eke, 2008). It is considered that price differences concentrated in long-haul flight networks or specific regions offer opportunities that could create cost advantages (Ro et al., 2009). However, it is stated that these price differences alone are not decisive, as the increase in weight and the associated increase in fuel consumption resulting from carrying excess fuel are also taken into account in decision-making processes (Fezans & Jann, 2017). Therefore, it is seen that fuel price differences between airports are considered an important decision variable within airline cost minimisation strategies, evaluated by taking into account economic analyses and operational constraints (Tabernier et al., 2021).

It is known that the practice of tankering has multidimensional effects on airlines' cost management and operational planning processes. From an economic perspective, it is stated that the aim is to reduce total fuel costs by purchasing additional fuel from lower-cost airports in order to take advantage of fuel price differences between airports (Nangia, 2006; Mao & Eke, 2008). It is noted that this approach enables significant cost advantages to be achieved, particularly on specific routes and at airport pairs with distinct price differences (Kang & Hansen, 2018). However, it is known that carrying excess fuel increases aircraft weight, leading to additional fuel consumption during flight. When evaluated from an operational perspective, this situation is stated to impose various constraints on elements such as flight performance, take-off weight limits, range planning, and load capacity (Fezans & Jann, 2017). It is particularly noted that carrying additional fuel in operations close to maximum take-off weight may result in limitations on cargo or passenger capacity (McConnachie et al., 2013). From an environmental perspective, it is considered that the additional fuel consumption resulting from carrying excess fuel leads to increased carbon emissions, and that this situation may produce outcomes that conflict with sustainable aviation policies (Tabernier et al., 2021). In recent years, with the strengthening of policies aimed at reducing carbon emissions by international aviation authorities and environmental regulatory bodies, the environmental impacts of tankering practices have been increasingly debated (Deo et al., 2020; Shen et al., 2024). In this context, it is stated that tankering decisions should be evaluated not only on the basis of economic benefits but also by considering operational efficiency and environmental sustainability dimensions together.

Despite the growing body of literature on airline cost management and fuel optimization, existing studies largely address economic efficiency or operational constraints separately, with limited integration of environmental considerations. In particular, there is a lack of dynamic and data-driven models that simultaneously evaluate cost advantages, operational limitations, and sustainability concerns within tankering practices. This gap has become more critical in light of recent developments in carbon emission regulations and sustainability-oriented policies in aviation. Accordingly, the research problem of this study lies in the absence of an integrated framework that captures the multidimensional nature of tankering decisions. Addressing this problem is essential not only for improving cost management strategies in the airline industry but also for contributing to current debates in the social sciences on sustainable decision-making and the evolving role of data-driven management practices. In this context, previous studies such as Singh & Sharma (2015) and Lee et al. (2018) have been reviewed to establish the theoretical and empirical foundation of the study.

This research will create a dynamic tankering model that seeks to reduce airline fuel expenditures. To achieve this goal, the research began with a literature review of fuel expenditures, fuel price differentials, and the use of tankering in the airline industry, followed by identifying the key variables involved in decision-making processes related to airline operations. Next, costs and other dynamic variables (e.g., price of fuel at various airports, distance flown, type of aircraft, fuel burn rate, and excess fuel transport consumption) associated with the various costs and/or benefits of tankering in the airline industry were input into the model. Within the model, the relationship between the cost benefit of acquiring additional fuel at an airport where fuel is less expensive versus the additional amount of fuel used to transport excess fuel will be analyzed in terms of cost-benefit calculus. Finally, in this context, the breaking point value where the decision to utilize tankering becomes economically meaningful will be calculated, and the impacts of changing scenarios on the decision making mechanism will be evaluated. Results of this study provided evidence, that when fuel price difference between the price where a flight originates versus the price where that flight will land exceeds a certain threshold, using tankering can affect total fuel cost. In addition, distance traveled, aircraft type and additional fuel consumption due to added fuel also play an important role in the decision-making process. The results of this analysis indicate that the dynamic tankering model can serve as a decision support tool in operational planning and can assist in optimizing fuel costs for airlines. Furthermore, this model was also seen as providing an adaptable mechanism for flexible decision-making by allowing for adjustments to take into account different types of routes and price structures.

Literature Review

Cost management in the aviation sector is of strategic importance, particularly due to the high proportion of fuel costs within total operating costs. It is observed that the majority of cost optimisation efforts in airline operations focus on reducing fuel consumption and developing fuel procurement strategies. It is stated that fuel costs in the aviation sector can constitute approximately one-third of total operating expenses, making fuel management a critical element in operational decision-making processes (Baker et al., 2002; Smith et al., 2004). Therefore, it is stated that cost management in airline companies has evolved from being solely an accounting-based activity to becoming an integrated decision-making mechanism within operational planning processes (Guerreiro et al., 2013; Singh et al., 2019).

In this context, it is observed that data analytics and operations research methods are increasingly being used in a significant portion of studies on cost management. It is stated that cost estimation models have become more dynamic, particularly through the integration of big data analytics and decision support systems into operational planning processes (Hubert et al., 2015; Hassan et al., 2021). In addition, it is stated that optimisation models aimed at reducing fuel consumption are widely used in flight planning processes and that route planning, fleet management and fuel supply strategies are evaluated together through these models (Deo et al., 2020; Shen et al., 2024).

The literature review suggests that fuel price differentials between airports are amongst the most important drivers of aviation operational fuel costs. As mentioned, the fuel prices of different airports significantly differ according to tax policies, local competitors and supply chain (Smith & Kunz, 2007; Wang et al., 2016). This phenomenon has been key for airline companies, making fuel procurement strategies one of the most crucial parts of operational planning processes. More specifically, it is said that by moving to procure fuel from airports with lower prices of fuel the operational costs can be reduced (Nangia, 2006; Mao & Eke, 2008). Research done in this context shows that differences in fuel prices can yield large cost savings under certain conditions for airlines (Ro et al., 2009; Kang & Hansen, 2018). Tankering, which is one of the most commonly used operational strategies in the industry to exploit fuel price variations, is defined as follows. It consists of buying extra fuel at cheap airport and utilising it when flying out from the more expensive one (Mao & Eke, 2008). Recall that previous literature shows tankering offers substantial cost savings, especially in certain route structures and airport pairs with considerable variance in fuel pricing (Kang & Hansen, 2018; Tabernier et al., 2021). Nevertheless, it is mentioned that there are no single economic evaluations for the application of tankering and this factor is also affected by operational limitations (Thomas et al., 2014; Fezans & Jann, 2017).

One of the most important factors in evaluating tankering applications is the additional fuel consumption effect caused by carrying excess fuel during flight. In the literature, this situation is generally referred to as the fuel penalty concept. It is known that the additional fuel taken on board increases the total aircraft weight, leading to additional fuel consumption during flight (Fezans & Jann, 2017; McConnachie et al., 2013). Therefore, it is stated that for tankering to provide economic advantages, the fuel price difference must exceed the additional consumption costs associated with carrying excess fuel (Tabernier et al., 2021). In this context, it is observed that break-even analyses and optimisation models are widely used in the literature to evaluate tankering decisions (Tsukerman et al., 2018; Zhu & Li, 2021). Furthermore, it is seen that the environmental impacts of these practices, as well as their economic ones, have become an important topic of discussion in the literature. Due to the increase in international regulations aimed at reducing carbon emissions in the aviation sector, operational fuel consumption has become a critical issue in terms of environmental sustainability (Deo et al., 2020; Shen et al., 2024).

Carrying excess fuel leads to more fuel consumption and contribute to increased emissions carbon dioxide, so several studies call for balance between the economic benefits and the environmental costs associated with fuel carriage (i.e., tankering); see (Tabernier et al., 2021; Yılmaz et al., 2021). Over the last few years, tankering decision-making has been examined in the aviation literature using improved optimisation modelling and decision-support systems as opposed to traditional/less complex planning methods. Recent works have developed dynamic decision-making models that incorporate multiple factors related to tankering such as fuel prices, flight distances, aircraft performance capabilities, and operational limitations (Waishek et al., 2009; Wang et al., 2016). It has also been noted that artificial intelligence-based and data analytics-based fuel optimisation models are beginning to be developed and that such models have significant potential for reducing airline’s operational costs (Bhattacharyya & Salim, 2015; Hassan et al., 2021; Yoo et al., 2026).

Studies conducted in the Turkish context also reveal that fuel management in aviation operations is an important area in terms of cost optimisation. In particular, studies utilising operations research and optimisation techniques contribute to the development of strategic decisions aimed at reducing fuel costs for airline operators (Gürsoy & Alptekin, 2023; Tuna, 2025). These studies reveal that fuel costs in the aviation sector should be evaluated not only in economic terms but also in terms of operational efficiency and sustainability. Consequently, it is understood that there is a need for research such as the present study in the literature.

Conceptual Framework

The conceptual framework of the study is based on a holistic approach to the relationships between fuel management, cost optimisation, tankering practices and environmental impacts in aviation operations (Singh et al., 2019; Hassan et al., 2021). It is stated that fuel costs are one of the largest items within total operating expenses in airline operations and, therefore, it is considered necessary to evaluate fuel management processes in conjunction with operational planning (Baker et al., 2002; Kang & Hansen, 2018). In this context, it is stated that tankering plays an important role among strategies aimed at reducing fuel costs (Nangia, 2006; Mao & Eke, 2008).

The tankering practice is based on taking advantage of differences in fuel prices between airports by obtaining additional fuel from airports with lower prices and using this fuel in subsequent flight segments (Mao & Eke, 2008; Kang & Hansen, 2018). However, carrying excess fuel increases aircraft weight, leading to additional fuel consumption during flight and resulting in an additional cost effect referred to in the literature as fuel penalty (Fezans & Jann, 2017; Tabernier et al., 2021). Therefore, it is emphasised that for tankering to provide economic advantages, the price advantage obtained must exceed the additional consumption costs associated with carrying excess fuel (Kang & Hansen, 2018; Tabernier et al., 2021). At this point, break-even analysis is considered an important analytical tool used in evaluating tankering decisions and provides a break-even point that reveals the balance between the fuel price difference and the additional consumption cost (Guerreiro et al., 2013; Tsukerman et al., 2018).

In tankering decision models developed for airline operations, it is stated that the economic balance in question is analysed based on variables such as route characteristics, aircraft type, fuel consumption rates, and operational constraints (Guerreiro et al., 2013; Kang & Hansen, 2018). In recent years, with the strengthening of policies towards sustainability and carbon emission reduction, the environmental impacts of tankering practices have been discussed more extensively, and situations requiring a balance between economic advantages and environmental costs have come to the fore (Deo et al., 2020; Tabernier et al., 2021). In this context, it has been demonstrated that tankering decisions must be addressed in terms of their economic, operational, and environmental dimensions by jointly evaluating fuel management, tankering practices, the fuel penalty effect, break-even analysis, and the relationship with carbon emissions (Deo et al., 2020; Shen et al., 2024).

Fuel Management and Cost Optimization in Aviation

Effective fuel management within the aviation industry is viewed as a key area for controlling operating costs because fuel costs can constitute a significant percentage of overall operating expense for the airline operator; and in some situations, fuel costs are outlined as one of the largest components of total operating expense (Baker, et al., 2002; Singh, et al., 2019). Therefore, through effective fuel management, airline operators can effectively control their operational costs (Guerreiro, et al., 2013; Hassan, et al., 2021). In this respect, fuel management constitutes both a technological planning process and a strategic management area which assists with business operations through minimisation of costs.

Therefore, fuel management in aviation is not considered merely an approach limited to reducing the amount of fuel consumed during flight. Many operational factors, such as flight route determination, weather conditions, aircraft type selection, and load planning, have a decisive impact on fuel consumption (Kang & Hansen, 2018). Consequently, fuel management processes in airlines are seen to be integrated with flight planning systems. This makes it possible to evaluate operational decisions based on more comprehensive data sets (Deo et al., 2020). In addition, it is known that analytical and mathematical models are widely used in studies aimed at reducing fuel costs. Through these models, the effects of factors such as flight distance, wind effect, aircraft performance characteristics, and air traffic density on fuel consumption are analyzed (Kang & Hansen, 2018; Zhu & Li, 2021). Thus, the goal is to create more efficient flight scenarios in operational planning processes.

It is stated that such analyses are used as an important decision support tool in the cost management processes of airline companies (Guerreiro et al., 2013). Similarly, fuel supply strategies are seen to play an important role in managing fuel costs. It is known that fuel prices at different airports can differ significantly. Therefore, it is understood that airline companies make decisions regarding which airports to obtain fuel from in line with economic evaluations (Nangia, 2006; Mao & Eke, 2008). Thanks to this approach, it is possible to identify alternatives that can provide cost advantages in operational planning processes (Kang & Hansen, 2018). Finally, the widespread adoption of digitalization and data analytics applications in the aviation sector has contributed to a more advanced structure in fuel management processes. Thanks to big data analytics and decision support systems, it has become possible to analyze flight data in detail (Hubert et al., 2015; Hassan et al., 2021). In this way, fuel consumption trends can be predicted more accurately and operational planning processes can be carried out in line with real-time data. Thus, fuel management is considered to have become a crucial management area at the heart of airline cost optimization strategies (Singh et al., 2019; Hassan et al., 2021).

Tankering Concept and Applications

In aviation operations, the concept of tanking is considered one of the important operational strategies developed to reduce fuel costs (Nangia, 2006; Mao & Eke, 2008). Tanking is based on taking advantage of the variability in fuel prices at different airports. In this practice, airlines plan to purchase additional fuel from airports where fuel is cheaper and use this fuel in subsequent flight segments (Mao & Eke, 2008; Kang & Hansen, 2018). Thus, the aim is to reduce total fuel costs by reducing or completely eliminating fuel purchases at airports where expensive fuel is required (Nangia, 2006; Kang & Hansen, 2018).

However, it is known that tankering is not considered solely as an economic choice. Additional fuel added to aircraft increases their total weight, leading to extra fuel consumption during flight. This necessitates careful consideration of tankering decisions in operational planning processes (Fezans & Jann, 2017; Tabernier et al., 2021). Therefore, airlines consider various operational constraints such as flight distance, aircraft type, maximum take-off weight, and payload capacity when making tanking decisions (Guerreiro et al., 2013; Kang & Hansen, 2018). On the other hand, tankering can be implemented in different operational forms. The literature generally mentions two main types of application: partial tankering and full tankering (Tabernier et al., 2021). In partial tankering, only a certain portion of the fuel needed for the next flight segment is supplied from a low-cost airport. In contrast, in full tanking, all fuel to be used in subsequent flight segments is sourced from low-cost airports, and fuel procurement from expensive airports is minimized as much as possible (Mao & Eke, 2008).

Another thing worth noting is that airlines depend on many different factors other than just the difference in price of gas when making decisions regarding fuel prices and tanking. Also, things like network structure (how many planes are flying where), the distance between two locations, how often airline flights are made and how flexible airline operations are do play a role in determining how much fuel airlines put in their tanks (Guerreiro et al., 2013, Yoo et al., 2026). Therefore, tanking is typically evaluated within the context of all of the operational planning strategies of an airline. It is also noted that tanking provides airlines with significant opportunities for cost savings, especially for airlines that operate as a network with multiple flights operating frequently to and from a location (Kang & Hansen, 2018). The environmental impact associated with tanking excess fuel has been discussed increasingly in recent years because it has been determined that carrying excess fuel leads to an increase in the amount of carbon emitted into the atmosphere through additional fuel consumption during the flight process (Tabernier et al, 2021; Deo et al., 2020). In light of this, international aviation regulators have underscored the importance of considering the environment when making decisions about tankering (Deo et al., 2020). Accordingly, tankering decisions should be assessed based on an analysis of the trade-off between economic benefits and operational efficiency, in addition to analysing the environmental sustainability of such operations (Tabernier et al., 2021).

Cost Effect of Carrying Excess Fuel

In aviation operations, carrying excess fuel is considered a factor that directly affects the cost structure due to the additional fuel consumption during flight (Fezans & Jann, 2017; Tabernier et al., 2021). Loading aircraft with more fuel than planned increases the total takeoff weight, causing the engines to generate more power during flight. Therefore, it is known that carrying excess fuel leads to additional fuel consumption during flight (Fezans & Jann, 2017). In the literature, this situation is expressed with the concept of fuel penalty and is used to describe the additional consumption effect caused by excess fuel (Tabernier et al., 2021).

In addition, it is known that the fuel penalty effect is not limited solely to additional fuel consumption. The increase in the aircraft's total weight can lead to increased aerodynamic drag and affect flight performance to a certain extent (Fezans & Jann, 2017). This situation can lead to a gradual increase in fuel consumption, especially on long-haul flights. Therefore, the expected economic advantage from carrying extra fuel must be evaluated together with the additional consumption cost (Deo et al., 2020; Tabernier et al., 2021).

On the other hand, the magnitude of the fuel penalty effect can vary depending on various operational variables. Factors such as aircraft type, engine efficiency, flight distance, cruising altitude, and meteorological conditions are stated to be decisive in determining the additional consumption caused by excess fuel (Kang & Hansen, 2018; Fezans & Jann, 2017). It is particularly noted that takeoffs with high weight can significantly increase fuel consumption in the initial stages of flight. Therefore, the cost impact of carrying excess fuel in airline operations is analyzed by considering flight characteristics (Tabernier et al., 2021). Furthermore, the fuel penalty effect is considered a critical parameter in the economic evaluation of tankering practices. For the additional fuel obtained from lower-priced airports within the tankering strategy to provide an economic advantage, the fuel price difference must be higher than the additional consumption cost caused by excess fuel (Guerreiro et al., 2013; Tabernier et al., 2021). Therefore, it is stated that the fuel penalty effect is calculated through analytical models in the process of determining tankering decisions and is used as an important variable in cost minimization analyses (Guerreiro et al., 2013).

In recent years, the strengthening of sustainability and carbon emission reduction policies in the aviation sector has led to more discussion of the environmental dimension of the fuel penalty concept. The additional fuel consumption resulting from carrying excess fuel can lead to increased carbon emissions (Deo et al., 2020; Tabernier et al., 2021). Therefore, it is emphasized that not only economic costs but also environmental impacts should be considered in operational planning processes. Within this framework, the fuel penalty effect is accepted as an important evaluation element in terms of fuel management and sustainability policies in aviation operations (Deo et al., 2020).

Break-Even Analysis and Tankering Decision Models

Break-even analysis is used as an important analytical tool in the economic evaluation of tanking applications in aviation operations (Guerreiro et al., 2013; Tsukerman et al., 2018). The break-even approach aims to determine the balance point between the fuel price advantage obtained as a result of tanking and the additional fuel consumption cost arising from carrying excess fuel (Tabernier et al., 2021). This analysis can reveal whether tanking provides an economic advantage for a given flight. Therefore, it is accepted that tanking decisions in airline operations should be evaluated not only based on fuel price differences but also taking into account additional consumption costs (Kang & Hansen, 2018).

Furthermore, break-even analysis establishes a threshold value that determines at what level the fuel price difference provides an economic advantage. If the fuel price difference between the cheaper and more expensive airports is lower than the additional consumption costs associated with transporting more fuel, tankering is considered not economically viable (Tabernier et al., 2021). Conversely, if the price difference exceeds this cost, the tankering strategy is considered to provide a cost advantage. Therefore, the break-even point is used as a fundamental reference point in determining tankering decisions (Guerreiro et al., 2013). Additionally, the construction of tanker decision models includes operational aspects. Studies have confirmed that aircraft type, flight distance, maximum take-off weight of the aircraft, rate of fuel consumption, and capacity of the cargo hold can all influence tanker decisions (Kang & Hansen; 2018, Deo et al.; 2020). As such, the authors suggest that these operational variables will be included in the same decision models and analyzed economically across all flight scenarios. According to the authors, incorporating both operational and economic variables into tanker operation models will allow for more accurate assessment of the results of tanker operation on various types of flights and under different operating conditions (Tsukerman et al.; 2018).

It is known that airlines utilize mathematical optimization models and decision support systems to support tankering decisions. Through these models, fuel prices, flight distances, aircraft performance values, and operational constraints are analyzed together, aiming to determine the lowest-cost fuel plan (Guerreiro et al., 2013; Zhu & Li, 2021). Linear programming and heuristic optimization methods, in particular, are frequently used in the development of tankering decision models. This approach enables more rational and data-driven decisions in operational planning processes (Zhu & Li, 2021).

In recent years, the widespread adoption of digitalization and data analytics applications in the aviation sector has contributed to a more dynamic structure for tanking decision models. Analysis of real-time fuel price data and operational flight data has led to more effective integration of tanking decisions into flight planning processes (Hassan et al., 2021; Yoo et al., 2026). Thus, decision models based on break-even analysis are considered an important tool in airline companies' cost optimization strategies and contribute to a more systematic approach to fuel management processes.

The Relationship between Tankering and Carbon Emissions

It is known that there is a direct relationship between fuel consumption and carbon emissions in the aviation sector. Significant amounts of carbon dioxide emissions are released as a result of the combustion of aviation fuel used in aircraft engines. Therefore, an increase in fuel consumption levels in aviation operations leads to an increase in carbon emissions (Deo et al., 2020; Shen et al., 2024). This situation necessitates the evaluation of fuel management practices not only in terms of economic costs but also in terms of environmental impacts (Tabernier et al., 2021).

Tankering is known as an operational strategy aimed at achieving cost advantages by taking advantage of fuel price differences (Nangia, 2006; Mao & Eke, 2008). However, loading aircraft with more fuel than needed increases the total aircraft weight and can lead to additional fuel consumption during flight (Fezans & Jann, 2017). This shows that carrying excess fuel can indirectly lead to increased carbon emissions. Therefore, it is stated that the environmental impacts of tankering practices should be considered in addition to their economic benefits (Tabernier et al., 2021).

However, the environmental impacts of tankering operations are not always at the same level. Factors such as flight distance, aircraft type, engine efficiency, and operational conditions are known to influence the amount of additional fuel consumption caused by carrying excess fuel (Kang & Hansen, 2018; Deo et al., 2020). Therefore, it is stated that in some operational scenarios, tankering operations may cause limited additional emissions. Conversely, it is noted that the increase in emissions can become more pronounced, especially in long-distance flights or when large amounts of additional fuel are carried (Tabernier et al., 2021).

On the other hand, in recent years, international regulations aimed at reducing carbon emissions in the aviation sector have been strengthened. It is known that the carbon balancing and reduction mechanisms developed by the International Civil Aviation Organisation have led to closer monitoring of the emission performance of airlines (Deo et al., 2020; Shen et al., 2024). In line with these developments, it is understood that airline operators are placing importance on assessing the environmental impacts of their operational decisions.

In this context, it is considered that tankering practices should be addressed not only as a means of reducing fuel costs but also within the framework of sustainable aviation policies. As the additional fuel consumption caused by carrying excess fuel can lead to increased carbon emissions, a balance must be struck between economic advantage and environmental cost in operational planning processes. Therefore, it is stated that tankering decisions should be evaluated by considering both cost optimisation and environmental sustainability targets (Tabernier et al., 2021; Deo et al., 2020).

Method

This study aims to develop a dynamic tankering model to minimise fuel costs in aviation operations. A quantitative analysis approach was adopted within the scope of the research, and a mathematical modelling method was used to reveal the economic decision mechanism. In order to determine whether the tankering decision provides economic advantages, fuel price differences and the additional consumption cost associated with carrying excess fuel were evaluated together (Guerreiro et al., 2013; Kang & Hansen, 2018). In this regard, an analytical decision model was developed by utilising fuel consumption models and operational fuel planning approaches found in the literature (Fezans & Jann, 2017; Tabernier et al., 2021). The model was used to analyse the cost outcomes of tankering under different fuel price scenarios.

In the research design, the fundamental variables influencing the decision to tankering were first identified. Within this scope, fuel prices between the departure and arrival airports, flight distance, aircraft type, and the additional consumption effect associated with carrying excess fuel were included in the model. The difference in fuel prices between airports was considered the primary determinant of economic advantage (Mao & Eke, 2008). However, the additional fuel consumption resulting from increased aircraft weight due to excess fuel carriage was evaluated within the framework of the fuel penalty approach (Fezans & Jann, 2017). Thus, the economic advantage of the tankering practice and the additional cost incurred by excess fuel carriage were analysed together.

The calculation of the fuel price difference and the determination of the additional consumption coefficient were addressed as fundamental steps in the mathematical formulation of the model. The fuel price difference was calculated by considering the unit fuel costs between the departure airport and the arrival airport. The w coefficient, which represents the additional consumption caused by excess fuel carriage, has been included in the model as a parameter representing the effect of the increase in aircraft weight on fuel consumption (Kang & Hansen, 2018; Tabernier et al., 2021). It has been accepted that, for tankering to be economically meaningful, the fuel price difference must be higher than the additional consumption cost. Within this framework, the break-even point condition is expressed by the inequality $P_B > P_A(1+w)$. This inequality ensures that the fuel price at the destination airport is evaluated together with the fuel price at the departure airport and the additional consumption coefficient (Guerreiro et al., 2013).

The dynamic tankering algorithm developed in the study was designed to enable the systematic evaluation of tankering decisions. Within the scope of the algorithm, a decision flow structure was first established, and steps were defined to determine whether the tankering application was economically advantageous. In this process, fuel prices, flight distance, aircraft performance values, and additional consumption coefficient were used as input parameters. Subsequently, the total fuel cost that would arise if tankering were applied was calculated using mathematical formulas, and the result obtained was compared with the situation where tankering was not performed. The application of the developed algorithm was carried out on an Excel-based calculation tool, enabling the model to be easily analysed under different scenarios (Zhu & Li, 2021).

The dataset used in the study is based on sample operational scenarios created to demonstrate the applicability of the model. Fuel price examples for different airports have been included in the model, and aircraft performance parameters have been defined based on specific aircraft types. Furthermore, the maximum take-off weight and maximum landing weight limits, which must be considered in flight operations, were also addressed in the model as operational constraints. The w coefficient, which represents the additional consumption caused by excess fuel carriage, was calculated by considering fuel consumption coefficients found in the literature (Fezans & Jann, 2017; Kang & Hansen, 2018).

Within the scope of the model application, an Excel-based dynamic tankering calculation tool was developed and the model's results were analysed under different operational scenarios. The first scenario considered a situation where tankering was not implemented and evaluated an operational structure where fuel was procured in the required quantities at each location. The second scenario examined an operational model where tankering was implemented, considering situations where fuel price differences provided economic advantages. Comparative results were obtained by calculating the total fuel cost, additional consumption due to excess fuel carriage, and net cost advantage for both scenarios (Guerreiro et al., 2013; Tabernier et al., 2021).

In the final stage, a sensitivity analysis was conducted to examine the sensitivity of the model results to different parameter changes. Within the scope of this analysis, the impact of changes in fuel price differences on the tankering decision was evaluated. Additionally, the effect of changes in the additional consumption coefficient on the model results was examined. Furthermore, the effect of changes in flight duration and distance on the economic advantage of the tankering application was analysed. The results revealed how the model performed under different operational conditions and demonstrated that the dynamic tankering model offers a decision support tool that can be used to optimise fuel costs in airline operations (Zhu & Li, 2021; Shen et al., 2024).

Research Design

This study develops a dynamic fuel tankering decision model aimed at minimizing fuel costs in airline operations. Fuel tankering refers to the strategy of carrying additional fuel from an airport where fuel prices are lower in order to reduce or avoid purchasing fuel at a subsequent airport where prices are higher. However, carrying additional fuel increases aircraft weight, which in turn leads to additional fuel consumption during flight. Therefore, the economic feasibility of tankering must be carefully evaluated.

The proposed model evaluates the economic advantage of tankering between two airports by considering fuel price differences and the additional fuel consumption caused by extra weight. In addition to economic factors, the model incorporates operational constraints such as aircraft performance limitations and safety requirements to ensure realistic operational applicability.

The research framework consists of three main stages:

- Development of the mathematical model for tankering decisions,
- Design of the dynamic tankering decision algorithm,
- Implementation of an Excel-based decision support tool and scenario analysis.

This structure allows the model to determine whether tankering is economically beneficial while considering operational constraints.

Mathematical Formulation of the Mode

The model considers a flight between two airports. Airport A represents the departure airport, while airport B represents the destination airport. The key parameters used in the model are defined as follows:

P_A : unit fuel price at airport A (e.g., TL/kg)
P_B: unit fuel price at airport B
F_{trip} : minimum fuel required for the A–B flight

F_{ret} : fuel planned to be taken at airport B for the next flight segment
$F_{max\_tankering}$: maximum additional fuel that can be carried from airport A within operational limits
w : additional fuel consumption coefficient representing the extra fuel burned to carry 1 kg of additional fuel

Carrying additional fuel increases the aircraft's weight, which results in additional fuel consumption during the flight. Therefore, the economic benefit of carrying extra fuel must consider both the fuel price difference and the additional fuel burned due to the increased weight.

If 1 kg of additional fuel is taken from airport A, the net economic benefit can be expressed as follows:

$$Net\ Gain = (P_B - P_A) - w * P_A$$

This expression represents the difference between the savings obtained by avoiding fuel purchase at airport B and the cost associated with transporting the additional fuel.

Tankering is economically beneficial when the net gain is positive. Thus, the break-even condition is given as:

$$(P_B - P_A) > w * P_A$$

Rearranging this inequality yields the fundamental decision rule of the model:

$$PB > PA\ (1 + w)$$

If this condition is satisfied, carrying additional fuel from airport A is economically advantageous.

Dynamic Tankering Algorithm

The developed model uses an algorithmic structure to determine the tankering decision. The algorithm first collects the required inputs, evaluates fuel price differences, and finally determines whether tankering should be applied.

The main inputs used in the algorithm include:

- Fuel prices at airports A and B
- Additional fuel consumption coefficient (www)
- Fuel planned to be taken at the destination airport
- Maximum additional fuel allowed by aircraft operational limits

The algorithm first calculates the critical price difference:

$$\Delta P_{critical} = w * P_A$$

Then, the actual fuel price difference is calculated as:

$$\Delta P_{actual} = P_B - P_A$$

These two values are compared to determine whether tankering is economically feasible. If:

$$\Delta P_{actual} \leq \Delta P_{critical}$$

tankering is not economically advantageous, and the aircraft only takes the required fuel for the flight from airport A. If:

$$\Delta P_{actual} > \Delta P_{critical}$$

tankering becomes economically advantageous, and additional fuel may be loaded at airport A.

The amount of additional fuel that can be carried is determined as:

$$F_{extra} = min(F_{ret}, F_{max\_tankering})$$

This ensures that the additional fuel carried does not exceed either the required fuel for the next flight segment or the aircraft's operational limits.

Excel-Based Model Implementation

The proposed algorithm was implemented as an Excel-based decision support tool. In the model, users enter parameters such as fuel prices, flight requirements, and aircraft operational limits. The Excel formulas automatically calculate the break-even condition and determine whether tankering should be applied.

If tankering is feasible, the model calculates the optimal additional fuel amount and the total fuel to be loaded at the departure airport. This structure enables rapid evaluation of different routes and fuel price scenarios.

Data Set and Assumptions

The dataset used in the model application includes representative fuel price values obtained from different airports. These values were used to simulate realistic operational conditions.

Aircraft performance limitations such as Maximum Takeoff Weight (MTOW) and Maximum Landing Weight (MLW) were considered to determine the maximum allowable tankering fuel. Additionally, the additional fuel consumption coefficient w was determined based on typical values reported in the literature.

To ensure operational feasibility, several constraints were incorporated into the model, including:

- Total takeoff weight must not exceed MTOW
- Planned landing weight must not exceed MLW
- Fuel, passenger, and cargo distribution must remain within center-of-gravity limits
- Airport performance conditions (runway length, temperature, elevation) must be suitable
- Airline operational procedures and regulatory restrictions must allow tankering operations

If these conditions are satisfied, tankering can be implemented.

When tankering is applied, the total fuel loaded at airport A is calculated as:

$$F_A = F_{trip} + F_{extra}$$

If tankering is not applied, the fuel plan becomes:

$$F_A = F_{trip}$$
$$F_B = F_{ret}$$

Thus, the model integrates both economic and operational considerations in determining the optimal tankering strategy.

Model Application

Excel-Based Dynamic Tankering Calculation Tool

The proposed tankering model was implemented using an Excel-based calculation tool designed to support operational fuel planning decisions. The tool enables users to input key parameters and automatically determine whether tankering is economically advantageous.

The main inputs used in the Excel model include:

- fuel price at departure airport (P_A)
- fuel price at destination airport (P_B)
- minimum fuel required for the flight (F_{trip})
- fuel planned for the next flight segment (F_{ret})
- maximum allowable tankering fuel ($F_{max\_tankering}$)
- additional fuel consumption coefficient (w)

Based on these inputs, the Excel model calculates the critical price difference and evaluates the break-even condition. If the condition is satisfied, the model determines the optimal amount of additional fuel to be carried from the departure airport.

This tool allows airlines to perform rapid evaluations of tankering decisions for different flight routes and fuel price scenarios.

Scenario 1: No Tankering Case

In the first scenario, the fuel price difference between airports does not justify tankering. In this case, the actual price difference is smaller than or equal to the critical price difference:

$$\Delta P_{actual} \leq \Delta P_{critical}$$

Therefore, carrying additional fuel is not economically beneficial.

Under this condition, the aircraft loads only the required trip fuel at airport A:

$$F_A = F_{trip}$$

The fuel required for the next flight segment is then purchased at airport B:

$$F_B = F_{ret}$$

This scenario typically represents situations where fuel prices between airports are similar or where the additional fuel consumption caused by carrying extra fuel offsets the potential savings.

Scenario 2: Economic Tankering Case

In the second scenario, the fuel price at the departure airport is significantly lower than at the destination airport.

In this case, the following condition holds:

$$\Delta P_{actual} > \Delta P_{critical}$$

Therefore, tankering becomes economically advantageous.

The total fuel loaded at airport A is then calculated as:

$$F_A = F_{trip} + F_{extra}$$

where the additional fuel amount is determined as:

$$F_{extra} = min(F_{ret}, F_{max\_tankering})$$

By carrying additional fuel from the cheaper airport, the airline reduces the amount of fuel that must be purchased at the more expensive airport, thereby lowering total fuel costs.

Comparative Results

The results of the two scenarios were compared to evaluate the economic impact of tankering strategies. The comparison was conducted based on three key criteria:

Fuel Cost

Total fuel cost was calculated by considering the amount of fuel purchased at each airport and the corresponding fuel prices.

Additional Fuel Consumption

When tankering is applied, the aircraft consumes additional fuel due to the extra weight carried during the flight.

Net Economic Benefit

The overall economic benefit of tankering can be expressed as:

$$\textit{Net Benefit} = \textit{Fuel Cost Savings} - \textit{Additional Fuel Consumption Cost}$$

The results indicate that tankering can provide significant cost advantages when fuel price differences between airports are sufficiently large.

Sensitivity Analysis

A sensitivity analysis was conducted to evaluate how changes in key parameters affect the tankering decision.

Fuel Price Difference

An increase in the fuel price difference between airports significantly improves the economic feasibility of tankering.

Additional Fuel Consumption Coefficient (w)

Higher values of the additional fuel consumption coefficient reduce the economic benefit of tankering because more fuel is consumed due to the increased aircraft weight.

Flight Duration

Longer flight durations increase the additional fuel consumption associated with carrying extra fuel. As a result, the economic advantage of tankering may decrease on longer routes.
The sensitivity analysis demonstrates that the proposed model can effectively support decision-making under different operational conditions and fuel price scenarios.

Findings and Discussion

The application results of the dynamic tankering model developed within the scope of the study were evaluated in terms of economic gains. It was observed that when fuel price differences exceed a certain threshold value, the tankering application can provide a significant reduction in total fuel costs (Guerreiro et al., 2013; Tabernier et al., 2021). The model application revealed that operational costs could be reduced by decreasing fuel procurement from expensive airports through the use of additional fuel sourced from low-cost airports. However, it was also determined that carrying excess fuel leads to additional fuel consumption during flights, which can reduce the economic advantage achieved under certain conditions (Fezans & Jann, 2017). Therefore, it was concluded that for tankering to provide economic advantages, the fuel price difference must exceed the additional consumption costs associated with carrying excess fuel (Kang & Hansen, 2018).

When examining the consistency of the application results, it was observed that the model exhibited similar trends under different scenarios. It was determined that when the fuel price difference was low, the tankering application did not provide an economic advantage; conversely, as the price difference increased, the tankering strategy could create a cost advantage. Furthermore, it was determined that changes in flight distance and additional consumption coefficient have significant effects on the model results. This indicates that the model exhibits a structure sensitive to changes in operational parameters (Tsukerman et al., 2018).

When evaluating the validating aspects of the model, the results obtained were found to be consistent with theoretical expectations regarding the relationship between fuel consumption and costs in aviation operations. In particular, it was confirmed that the additional consumption effect associated with excess fuel carriage is a decisive factor in tankering decisions (Fezans & Jann, 2017). Furthermore, it was determined that the developed Excel-based calculation tool enables rapid and systematic analysis under different price scenarios. This indicates that the developed model can be used as a decision support tool in operational planning processes (Zhu & Li, 2021).

The findings obtained in this study show that the general trends are largely similar when compared to studies on tankering practices in the literature. The literature states that fuel price differences are one of the key determinants of tankering decisions (Mao & Eke, 2008; Guerrero et al., 2013). The findings obtained in this study also indicate that tankering can provide economic advantages when the fuel price difference exceeds a certain threshold value. However, it is understood that the findings emphasised in the literature, namely that the fuel penalty effect is an important factor limiting the economic efficiency of tankering applications, are also confirmed in this study (Tabernier et al., 2021).

Evaluating tankering from an operational perspective highlights tankering as a combination of positive and negative operational strategies. A significant operational benefit is the ability to create a cost advantage from using different prices for fuel (Kang & Hansen, 2018). However, carrying an increased amount of fuel beyond the required amount results in an aircraft being overweight, resulting in other impacts such as increased fuel consumption and performance of the flight (Fezans & Jann, 2017). Excess fuel carried can restrict carrying capacity of the aircraft, especially when operating near maximum takeoff weight. Therefore, tankering must be considered with respect to operational constraints when making decisions. Additionally, such practices must be addressed from a standpoint of performance, weight, and sustainability. The increase in the aircraft's weight directly affects the engine's performance and fuel consumption (Deo et al., 2020). As a result, increased fuel consumption due to the extra fuel carried can influence both financial costs as well as efficiency level of the operation. It is important to perform evaluations of tankering decision for their price advantages and for consideration of performance related to flights and/or operation efficiency.

In recent years, the strengthening of policies aimed at reducing carbon emissions in the aviation sector has led to increased discussion of the environmental impacts of tankering practices. The additional fuel consumption resulting from carrying excess fuel can lead to increased carbon emissions (Shen et al., 2024). This necessitates striking a balance between economic cost advantages and environmental sustainability goals. Therefore, it is stated that tankering practices should be evaluated not only in terms of cost minimisation but also in the context of carbon emissions and sustainable aviation policies (Tabernier et al., 2021; Deo et al., 2020).

Conclusion and Recommendations

In this study, a dynamic tankering model was developed to minimise fuel costs in aviation operations, and the economic effects of the model were analysed under different operational scenarios. The findings indicate that when fuel price differences exceed a certain level, tankering can reduce total fuel costs (Guerreiro et al., 2013; Tabernier et al., 2021). It was found that savings in operational costs can be achieved, particularly by reducing fuel purchases from expensive airports through the acquisition of additional fuel from low-cost airports. However, it was also observed that carrying excess fuel leads to additional fuel consumption during the flight, which can reduce the economic advantage to a certain extent (Fezans & Jann, 2017). Therefore, it was concluded that for tankering to provide economic advantages, the fuel price difference must exceed the additional consumption costs associated with carrying excess fuel (Kang & Hansen, 2018).

The model results indicate that the tankering practice does not provide the same level of advantage on every flight route. It has been determined that the tankering application can provide more significant economic benefits, particularly on flights between airport pairs with high fuel price differences (Mao & Eke, 2008). However, it is seen that the tankering application may be more advantageous on routes with short or medium flight distances, as the additional consumption effect caused by carrying excess fuel is limited. Conversely, it is assessed that the economic advantage may decrease in long-haul flights and operations requiring the carriage of large amounts of additional fuel due to the increase in additional consumption costs (Tabernier et al., 2021).

Based on the findings, several operational strategy recommendations have been proposed for airline companies. Firstly, it is stated that tankering decisions should be made not only based on fuel price differences but also by considering flight distance, aircraft type, fuel consumption rates, and operational constraints (Kang & Hansen, 2018). Furthermore, evaluating tankering practices through decision support systems integrated into operational planning processes could contribute to airlines managing their fuel costs more effectively (Zhu & Li, 2021). In addition, regular analysis of fuel prices and operational data would enable tankering decisions to be made more accurately and systematically.

For future research, it is considered that the model developed in this study can be adapted and extended to different operational conditions. In particular, analyses incorporating multi-leg flight routes may allow for a more comprehensive examination of the effects of tankering practices within the network structure (Tsukerman et al., 2018). Furthermore, due to increasing regulations on carbon emissions, incorporating a carbon tax into the model will contribute to the assessment of tankering decisions in terms of environmental costs (Deo et al., 2020; Shen et al., 2024). Furthermore, integrating the developed model with advanced optimisation software and operational planning systems is considered an important research area that could enable the development of more comprehensive and real-time decision support mechanisms (Zhu & Li, 2021).

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