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System Dynamic Model for Simulating Aviation Demand: Baghdad International Airport as a Case Study

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ABSTRACT

The aviation authorities have long been impacted by fluctuations in demand, which are often caused by the aviation industry's cyclical nature. It is affected mainly by many endogenous or exogenous variables. Despite that, the airport authorities and air carrier management make significant efforts to deal with fluctuating demand. This paper analyzed the factors influencing demand at Baghdad International Airport, based on the pertinent local socio-economic data such as "population size," "GDP," and "terrorism effect," as well as system-based factors related to aviation activities and airport characteristics for the past ten years, to develop a system dynamics simulation model by which the causes of fluctuation are highlighted in order to predict the magnitude and timing of the increment or decline in an offer to minimize losses to all parties in the airport system. The simulation results demonstrated very high goodness of fit with the actual data, producing R^2 values of 0.865 and 0.86 for the departing and arriving passengers, respectively. Even though Iraq's unstable political and economic situation led to the interaction between the different demand drivers, external factors have a bigger effect on the country's need for air travel, causing demand shocks that take a long time to recover from.

1. INTRODUCTION

Over the past three decades, Iraqi airports have been affected by several political and economic issues and external impacts such as wars and siege. Baghdad International Airport has suffered considerably, particularly after 2003, for it was considered a military facility. Since then, progress has slowed due to the surrounding situations that impede the aviation sector [1].

In this context, aviation authorities have long been impacted by fluctuations in travel demand, which are typically caused by seasonal fluctuations, external attacks, or mismanagement of available resources. Although airport authorities and air carrier administrations make significant efforts to meet the oscillated demand, mostly through a temporary increase in their offer in terms of human and material resources, these increments mostly overshoot the start of the demand increase and usually take time to fulfill the surge, which mostly decreases before the reduction of the supplemental offer.

Air transportation demand is of a cyclical nature (increases and decreases over the year or several years), and this is by its nature reflected in the airport's performance and response, in terms of facility congestion or delays in flights.

Three related factors are responsible for congestion at the airport. Firstly, demand fluctuations occur over different time periods (days or more). Secondly, it is linked to problems with the network. Finally, the flight schedules [2].

This study aims to create a system dynamics model to find out the real reasons for these fluctuations and simulate the potential behavior of demand in the Iraqi major hub represented by Baghdad International Airport.

2. LITERATURE REVIEW

2.1 Aviation demand forecast

Forecasts of demand in the civil aviation industry are essential inputs for a wide range of issues, including the expansion and improvement of airport infrastructure, the supply of aircraft, the availability of financial resources, etc. [3]. However, the aim of demand modeling and forecasting is to calculate an airline's share of the market; analyze costs and profits; estimate the number of passengers on certain routes in the network; and, evaluate the effects of operational capabilities on demand [4].

Forecast horizons in the aviation industry are often short-term, medium-term, and long-term: 1, 5, and (20 - 25 years) respectively [5].

The process selection depends on the forecasting situation, some of which are better suited for short-term predictions while others are better for long-term forecasts. Some approaches are better at forecasting traffic on existing routes or markets, whereas others are better at studying and forecasting traffic on new routes. Some techniques are suitable for analyzing the potential impact of minor changes in transportation infrastructure, whereas others are appropriate when major changes are occurring. Forecasting methods also differ in terms of the need for data, the cost of acquiring the data, the time required to prepare a prediction, and the cost of making an estimate [6].

Additionally, forecasting approaches are divided into three categories based on their methodology: Quantitative, qualitative, and decision analysis. Quantitative techniques primarily use previous patterns to forecast future numerical data. The availability of historical data is required for quantitative forecasting approaches. These techniques are inapplicable if the necessary data cannot be gathered. In this case, qualitative methods may be used based on the judgment, intuition, and experience of some specialists or key persons. The third technique is a hybrid of the preceding two [7].

2.2 Cyclical nature of aviation markets

In general, air traffic is a service provided to travelers, the market for aviation suffers from the issue of the exemplary service industry, that is, being unable to store the service offered to the customer. In this respect, the aviation market's cycles are mostly endogenous, while exogenous influences only impact the cycle magnitude but are not responsible for the system's basic cyclical behavior [8].

The evolution of the aviation industry is strongly affected by its cyclical nature, whether it is endogenous or exogenous. To grasp these cycles, the crucial performance drivers must be examined. There are several exogenous factors: "Population, Domestic GDP, World GDP, the Consumer Price Index, the Producer Price Index, jet fuel prices, national average wage, and unemployment". As for the endogenous factors: the airport system and operating air carrier "ticket price and schedule", etc. [9].

Besides that, researchers have exhibited, that the price and the schedule are the most significant considerations between the different factors that affect customer choice for a particular airline. They are attempting to attract customers by creating and refining a schedule marked by a large number of destinations and regular flights to each of these destinations. However, a single airline flight's cost structure causes a condition opposite. Since the flight herself is the largest part of the total costs of an aircraft (direct operating expenses), the residual costs are minimal for any other passenger [10].

In this regard, the air carrier should try to fly to a particular destination at less recurrence and load the aircraft with as many passengers as possible maximize seat load factor. Combined with these elements, airlines face the fact that capacity preparation and scheduling are among the more important considerations for business development [8].

2.3 Forecasting with system dynamics "SD"

In the 1950s, Jay W. Forrester of the Massachusetts Institute of Technology] created system dynamics for the first time as a way whereby the dynamics of complex systems are understandable over time and presented in the form of graphs and mathematical equations [11].

The most important points of support provided by SD [12]:

a. An improved perceptual understanding of the dynamic nature of economic and industrial processes.
b. It illustrates how the main elements of an organization are linked to one another.
c. Anticipate the path of an organization's potential operations,
d. Improvements in the strategic and probable vision.

Forecasting using the SD program attracted significant interest from many researchers seeking to develop a reliable, time-varying model. In the Airport's environmental carrying capacity, Peng et al. have used the forecasting model to investigate the AECC's development features across several airports, utilizing the DPSR (driving force, pressure, state, response) model [13]. Kim et al. created a model for anticipating air passenger demand in order to determine the rising trend of the aviation industry in Korea [14]. Pierson has constructed a model of the airline business by examining how several factors interact to generate profit cycles [9]. Pierson and Sterman have created a dynamic model in the aviation industry with internal drivers such as capacity, supply, wages, salaries, and expenses. To investigate the reasons behind lucrative aviation cycles and devise a variety of approaches that decision-makers may take to counter them [15].

The SD technique was particularly useful in studying the factors that have a direct effect on demand and forecasting air travel demand by developing a methodical model for future systems [11, 16-22].

Two studies were performed to appreciate the dynamics behind the creation of secondary airports in Iraq's regional airport networks and the United States [23, 24].

For further studies relating to the SD method, Bramham has constructed a multi-level element map that reflects the business environment so that costs, safety, environment, and policy are the major elements determining the aviation industry's future [25]. Manataki and Zografos provided a decision-support tool for the airport lounge planning process, design, and administration [26]. Steverink and van Daalen designed a dynamic simulation model to ease information exchange on the variables and processes affecting airport selection [27]. Minato and Morimoto examined regional airports as business ecosystems and the development of a simulation model of the system and then suggested the formulation of optimum management methods for ensuring commercial sustainability at the airport [28]. Qin and Olaru proposed a system dynamics model to better understand the interplay between airports, airlines, and passengers [29]. Kleer et al. have modeled and analyzed the strategic operational movements of two air carriers under a variety of different conditions using "SD" [30]. Qin has found that government regulation is essential for an airport without competition from other modes because the airport revenues are positively related to the airport charge rate [31]. Oliviera has identified, simulated, and analyzed how airport management's strategic decisions and carriers' input impact airport revenues over time. In the short or medium-term projection, the airport manager's reaction to service level affects revenue, but it improves income and flight operations in the long-term forecast [32].

3. CASE STUDY AND MARKET AREA

It is one of the most important and major airports in Iraq, it was rehabilitated between 1979 and 1982 by French and British businesses, for both civilian and military use. It is located 16 kilometers west of Baghdad's city center. The airport is comprised of three passenger buildings (Samarra, Babil, and Nineveh), as well as the Karbala building, which is devoted to Hajj and Umrah pilgrims. The capacity of each building is 2.5 million passengers per year, and each of these buildings has six air bridges to transport passengers to aircraft.

The area around Baghdad International Airport that generates and attracts air service passengers is called the airport's market area. In this case, as shown in Figure 1, this airport might be affected by the middle area of Iraq, which is comprised of the city of Baghdad, and the five neighboring governorates, including Diyala, Saladin, Al Anbar, parts of Wasit, and Babil. This is because of a number of factors, such as accessibility, time and ground access trip, administrative jurisdiction, and flight frequency.

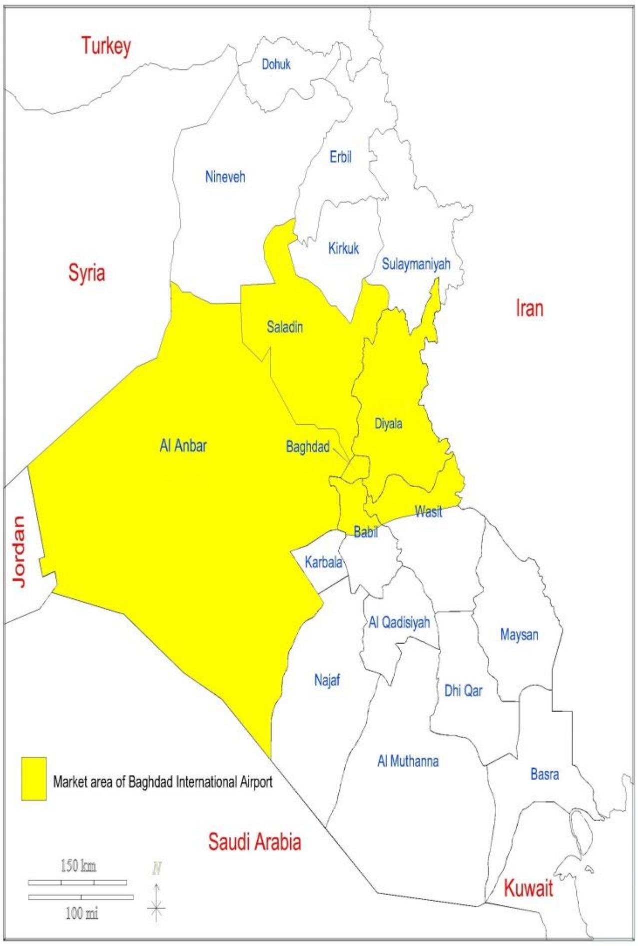


Figure 1. Market areas of Baghdad International Airport

4. DATA COLLECTION AND ANALYSIS

One of the important steps in scientific research is the process of data collection, as it helps to classify and analyze the information obtained according to the planned methodology in the form of results that can be used and applied to other related phenomena. In this regard, obtaining historical data was not a simple task; rather, it was varied and heterogeneous, since each governmental entity or department had data that differed from the other, in addition to the privacy of some data.

The data for this study obtained from Iraq's Central Organization for Statistics and Information Technology (COSIT) and the Ministry of Planning, included socioeconomic characteristics on regional population growth from 2010 to 2019 and gross domestic product (GDP) from as well as the aviation data; passenger movements, aircraft operations, delays of flights all over the analysis period.

In modeling the demand for air travel, the population is an essential factor, as it is in many local and international studies. It is likely that the demand for air travel will be directly related to the population. Figure 2 depicts the population size of Iraq's middle region, which has grown at a steady rate for the last 40 years.

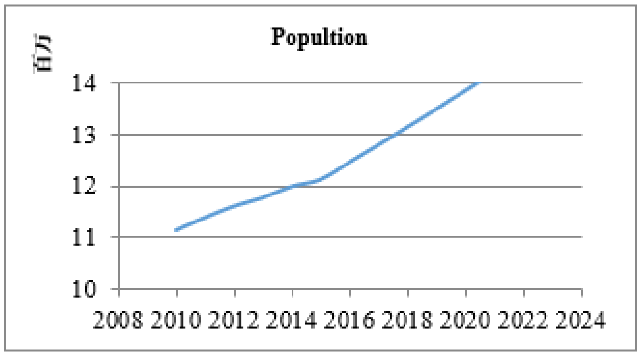


Figure 2. Population size of Iraq's middle region

GDP is one of the most critical factors that influence the tendency to fly in any state or region. Figure 3 shows that the GDP data (in millions) for this study was used 2 years before 2010 due to the fact that this influence on air traffic demand is indirect; rather, it appears gradually; that is, whether it grows or decreases, it goes through a period of time delay before becoming apparent. This situation is referred to as "information delay" in the system dynamic.

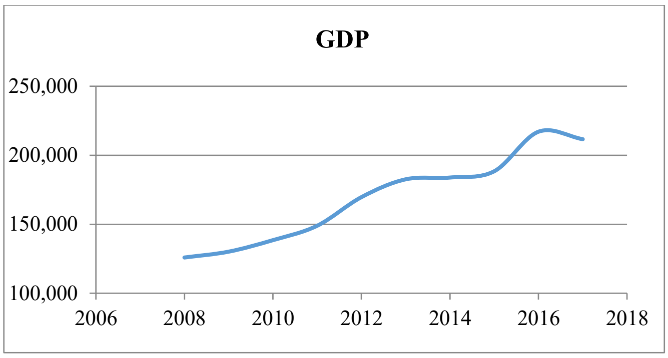


Figure 3. GDP statistics for Iraq (2008-2017)

5. SYSTEM DYNAMIC APPROACH

System dynamics, when used as a modeling tool, helps to describe a system as a feedback loop in a causality circle as well as in stock and flow diagrams. Using system dynamics models can be advantageous in a variety of ways, some of which are given below:

- Demonstrating the cyclical nature of air travel demand at the hub airport in Iraq.
- Design and development of analytical tools that may be used to evaluate and study crucial elements in a wide range of circumstances.
- Estimate the most effective strategy for meeting projected demand during the planning horizon, all possible policies implemented by all stakeholders are being tested.

This approach connects qualitative "causal loop diagrams" and quantitative models "Stock and flows diagrams". The qualitative models work best when they are developed with the participation of all key stakeholders and are communicated through causal loop diagrams (CLD). Model construction includes the establishment of a CLD, which connects entities through the use of causal relationships. As the diagram progresses, it becomes clear that there are feedback loops.

5.1 Causal loop diagram of basic model

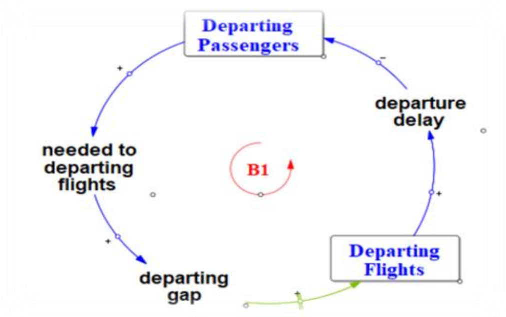
Basically, the system dynamics method adapts to the features of the airport as a facility in which a large number of elements interact with one another. As a result, the interrelationships between endogenous and exogenous variables have an impact on the cyclical demand. By defining how each element influences the other and, in turn, influences itself in a positive or negative reaction, causality is able to describe the qualitative situation of demand.

For a time-dependent study, causal loops inside modeling are used to repeat the input datasets of variables or formulas. A causal loop diagram is used to illustrate the fundamental relationships that influence air travel demand in Figure 4. The causes and effects of the structure variables are shown. More than one feedback loop has an impact on airport activities.

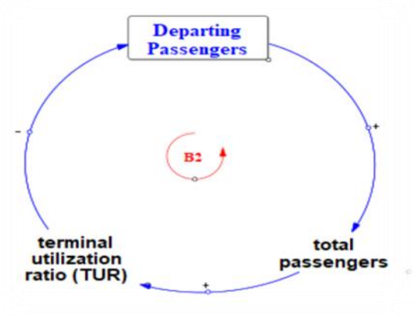
In general, the dynamic behavior of a system can be classified as "positive," "negative," "negative with delay," or a combination of these categories. A positive feedback loop (self-reinforcing, denoted in the system dynamic software by R) is the behavior that causes more change in the system in the same direction, which leads to exponential growth. Negative feedback loops (self-correcting or balancing, denoted in the system dynamic software by B) are relationships where a rise in one entity leads to a decrease in the other. Systems with balancing and reinforcing loops achieve more dynamic equilibrium [11]. In Baghdad International airport modeling, all of the feedback loops are negative.

As a simplification, there are four negative feedback loops in the diagram above:

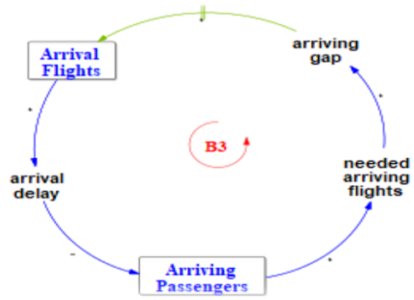
1. **B1 Loop:** Figure 4 (a) shows that during the peak season holiday breaks or religious visits, there are more passengers leaving Baghdad International Airport, which leads to more flights being needed a positive effect and that necessitates a period of time delay gab for supply to meet demand. This increasing, in turn, causes a delay in flights, which is bad for departing passengers a negative effect, because they have to wait longer for their flights.
2. **B2 and B4 Loop:** Figure 4 (b, d) the causal loop diagram indicates that if the number of departing or arriving passengers at Baghdad International Airport increases, the total number of passengers in the terminal building will raise (a positive effect), causing congestion, discomfort, and dissatisfaction for passengers (a negative effect).
3. **B3 Loop:** Figure 4 (c) is similar to the first loop; more passengers arrive at Baghdad Airport, which results in the need for more landing flights (a positive effect), which in turn necessitates a period of time "delay gab" for supply to catch up with demand. Due to a rise in demand, flights are delayed, which is undesirable for incoming passengers (a negative effect), as they have to wait longer for their flights to arrive as a result of the delay.



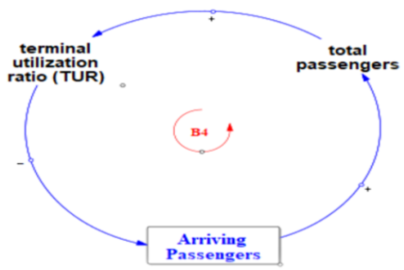
(a) First Loop



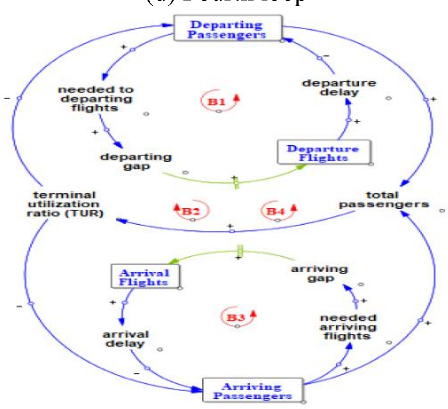
(b) Second loop



(c) Third loop



(d) Fourth loop



(e) Total loops

Figure 4. Causal loop diagram of basic aviation model

5.2 Stock and flow diagrams for the basic model

Stock and flow diagrams (SFD) are the quantitative phases of a system, which represent changes over time in the measurement and rate of each variable in the structure of a complex system. The basic model has four stocks (levels) that represent the "population, GDP Actual Effect, departing passengers, and arriving passengers". These levels establish a sub-model variable as well as external and auxiliary data.

The system dynamics simulating model was created by inserting the mathematical equation for each factor into the auxiliary equation that corresponds to it. On the other hand, the parameters that were incorporated into each model were treated as "lookup tables" for each variable that was used in the modeling. Figure 5 illustrates how these sub-modules are used to compute the activities associated with aviation, and the following sections provide a more in-depth description.

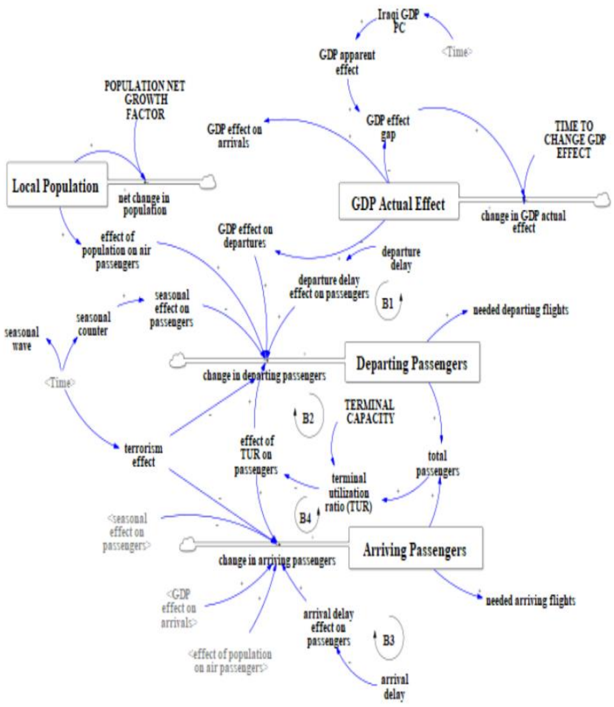


Figure 5. Stock and flow diagrams of the basic aviation model

5.2.1 Local population stock

The first stock in Figure 5 depicts the population of the airport market area. It is easy to build the model by calculating the net difference between births and deaths, as well as in-migration and out-migration. For more details, the population sub-model consists of the following elements:

First: Stock

• Local population = INTEG (net change in population, 1.116e+07) (1)

The monthly initial value of this stock was equal to the district's population in 2010, which was reported by the Ministry of Planning and Central Division for Statistics to have been 11,159,300 people.

Second: Flow

• Net change in population = Local Population* POPULATION NET GROWTH FACTOR (2)

In accordance with the previously stated constant monthly "POPULATION NET GROWTH FACTOR" of 0.001496, this flow represents the increase in population number in a unit of time during a given period of time.

Third: Auxiliary variable

• Effect of population on air passengers = Local population *0.2/12 (3)

This auxiliary determines the number of prospective air travel passengers as a percentage of the total population using the population distribution formula, which is approximately 0.20% per year.

5.2.2 Stock of Gross Domestic Product (GDP)

The second stock in Figure 5 explains the value of GDP over the past 120 months from 2010 to 2019. For more details, the GDP sub-model consists of the following elements:

First: Stock

• GDP Actual Effect= INTEG (change in GDP actual effect, 1) (4)

Second: Flow

• Change in GDP actual effect=GDP effect gap/TIME TO CHANGE GDP EFFECT (5)

Third: Auxiliaries

• GDP effect on arrivals=GDP Actual Effect*1 (6)

• GDP effect on departures=GDP Actual Effect*1 (7)

• Iraqi GDP PK = WITH LOOKUP(Time,([(0,4500)(120,6500)],(0, 4840),(12,4840),(24,5310),(36,5510),(48,5350),(60,5300),(72,5920),(84,5640),(96,5480),(108,5600),(120,5580))) (8)

• GDP apparent effect = WITH LOOKUP (Iraqi GDP PK, ([(4500,-1)-(6000, 2)], (4532.11, 0.486842), (6009.17, 1.97368))) (9)

• GDP effect gap= GDP apparent effect-GDP Actual Effect (10)

In the above element, the (TIME TO CHANGE GDP EFFECT is 24 months) was used in this study due to the fact that the GDP's influence on air traffic demand is indirect; rather, it appears gradually; that is, whether it grows or decreases, it goes through a period of time delay before becoming apparent, this situation is referred to as "information delay" in the system dynamic.

5.2.3 Departing passenger's sub-model

The third stock in Figure 5 depicts the organizational structure of the departing passengers. These model outputs will have a direct impact on the volume of passengers at the airport. The stock and flow, as well as the chain of auxiliary variables like "the aircraft's departure delays" and "the effect of a terminal utilization ratio," which are based on the airport system. Moreover, as exogenous characteristics, the socioeconomic variables on a local scale include "population size," "GDP," "seasonal," and "terrorism effect." All of these factors are organized to illustrate how they affect fluctuating passenger demand. A 120-month period is used to accumulate the stock, which is calculated based on the change rate of passengers and begins with the initial departure of passengers. This sub-model consists of the following elements:

First: Stock

• Departing Passengers = INTEG (change in departing passengers, 30000) (11)

30,000 passengers are assigned an initial value based on the average monthly departing passenger volume at the beginning in 2010.

Second: Flow

• Change in departing passengers = ((0.01*effect of population on air passengers*effect of TUR on passengers* GDP effect on departures* seasonal effect on passengers)-2*(1-departure delay effect on passengers))*terrorism effect (12)

This flow represents the change in departing passengers per unit of time governed by the effect of terrorism multiplied by the difference between (the effect of the population on air passengers multiplied by the effect of terminal utilization ratio on passengers, the effect of GDP on departures, and the seasonal effect on passengers) from the effect of departure delays on passengers.

Third: Auxiliaries

• Needed departing flights = Departing Passengers/99 (13)

To maintain a balance between demand and supply, airlines are increasing the number of flights in response to the growing number of passengers. This equation illustrates the relationship between the number of departing passengers and the average number of available seats on an airplane.

• Total passengers = Departing Passengers + Arriving Passengers (14)

• Departure delay effect on passengers = WITH LOOKUP(departure delay,([(0,0)(50000,1)],(45.8716,0. 995 614),(5963.3,0.912281),(11009.2,0.833333),(18348. 6,0.732456),(28287.5,0.570175),(35321.1,0.434211),(4281 .5 ,0.285088),(49847.1,0.122807))) (15)

• Effect of TUR on passengers = WITH LOOKUP (“terminal utilization ratio (TUR)”, ([(0,0) (1,1)],(0.0152905,0.745614) ,(0.556575,0.460 526),(0.63 3027,0.416667),(0.681 957,0.399123),(0.984 71,0.25))) (16)

• Terminal utilization ratio (TUR) = total passengers /TERMINAL CAPACITY (17)

Seasonal counter= ((Time/12)-INTEGER(Time/12)) *12 (18)

This auxiliary variable is computed using the high and low seasons, which occur virtually every year.

• As shown in the Figure 6, there is a lookup graph seasonal effect on passengers dependent on the seasonal counter.

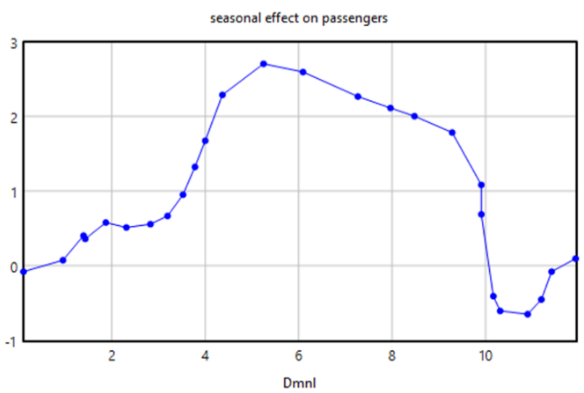


Figure 6. Effect of seasonal on passengers

In Figure 7, the impact of terrorism is determined using a lookup graph based on unit time.

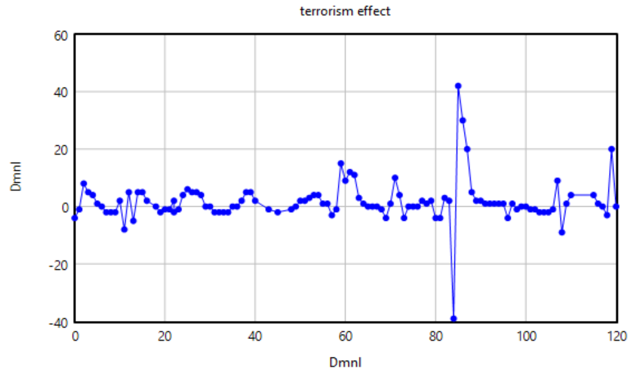


Figure 7. Effect of terrorism on passengers

5.2.4 Arriving passengers sub-model

The fourth stock in Figure 5 represents the arriving passengers' organizational structure. This output will have a direct effect on the airport's passenger volume. This flow chain includes auxiliary variables such as “aircraft arrival delays” and “the influence of a terminal utilization ratio”. On top of that, socioeconomic variables on a local level can be categorized by “population size,” “GDP,” “seasonal and terrorist effect”. All of these variables have been built to demonstrate their effect on fluctuating passenger demand. To simulate the change in the structure of the data, first-order information is used. The monthly stock was built up from the initial number of passengers arriving in January 2010 and ended in December 2019. This sub-model consists of the below elements:

First: Stock

Arriving Passengers= INTEG (change in arriving passengers, 33000) (19)

Second: Flow

Change in arriving passengers=((0.01*effect of population on air passengers*effect of TUR on passengers*GDP effect on arrivals*seasonal effect on passengers)-2*(1-arrival delay effect on passengers)) *terrorism effect (20)

Third: Auxiliaries

Needed arriving flights = Arriving Passengers/ 101 (21)

Arrival delay effect on passengers = WITH LOOKUP (arrival delay, ([(0,0)-(50000,1)],(91.7431,0.995614), (3516.82,0.95614),(8180.43,0.881579),(15443.4,0.77193),(2 3700.3,0.675439),(29357.8,0.570175),(34862.4,0.438596),(3 9908.3,0.320175),(49541.3,0.0394737))) (22)

6. MODEL RUN OUTCOMES AND DISCUSSION

Using the numbers of the base month as beginning values for the stocks of “Population”, “GDP”, “Departing passengers”, and “Arriving passengers”, the modeling of the system dynamics was run for a period of 120 months. The constants in this model were derived via several correlation evaluations between variables. In this model, the same approach was used to determine the shapes of the relations included in the lookup tables. In order to calibrate a number of model parameters, the system's general behavior was also considered. According to the external and system-based parameters, tow sub-models have been constructed to estimate the total number of passengers, the first is for departing passengers; the second is for arriving passengers.

As shown in Figure 8 the stock starts in month 1 approximately (30,139) passengers / month and ends in the month of 120 with (172,999) passengers / month. In addition, the simulation for departing passengers is extremely close to the actual data, which is apparent and logically the same in both instances.

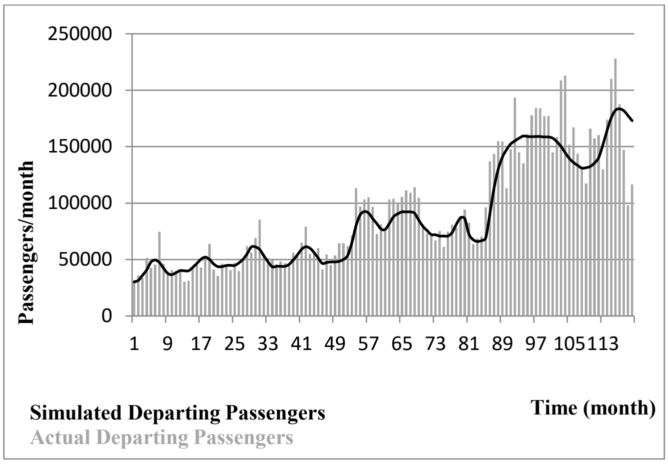


Figure 8. Comparison of actual and simulated data for departing passengers

Figure 9 reveals that the stock begins with about (33,140) passengers/month in month 1 and ends with nearly (176,233) passengers/month in month 120. Also, the simulated demand has a similar trend and is quite close to the used historical data, with one minor deviation from the path in 2014 due to the country's political situation (ISIS terrorist attacks), which was considered an emergency event that significantly impacted demand.

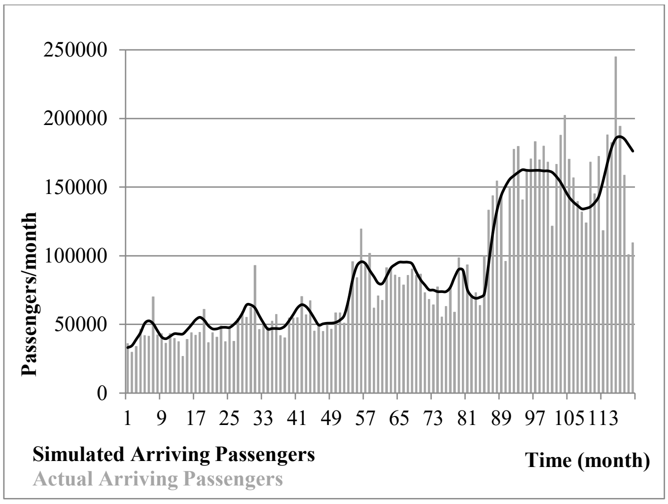


Figure 9. Comparison of actual and simulated data for arriving passengers

Figures 10 and 11 show the simulation is along the y-axis while the actual data is shown along the x-axis, to assess model fit and identify the extent to which a model can be applied to independent data based on socioeconomic characteristics and the airport system-based. According to the results of this evaluation, R^2 = 0.865 and 0.86. These high numbers indicate that the simulation model.

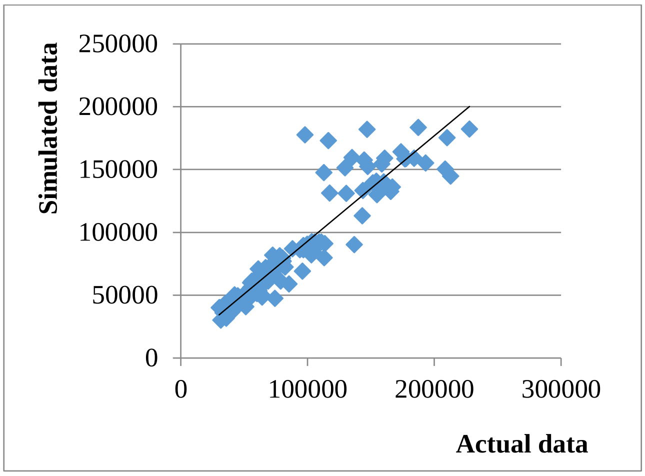


Figure 10. Correlation of actual and simulated data for departing passengers

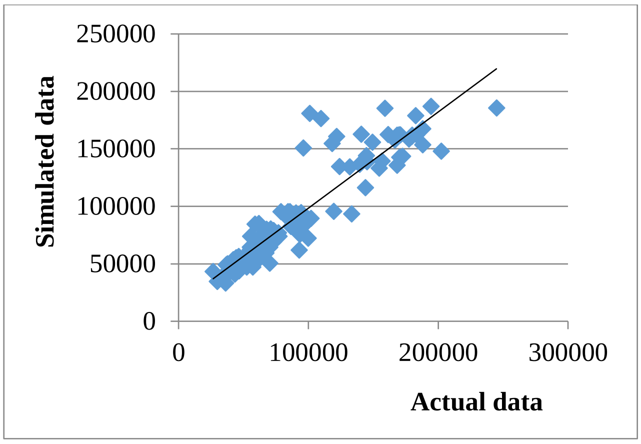


Figure 11. Correlation of actual and simulated data for arriving passengers

There were several criteria that directly and indirectly influenced demand, some of which had a significant effect and others had a minor impact, which is one of the primary causes of the oscillation of aviation demand, as with any other industry. During the research period, in general, the demand fluctuates with a noticeable increase (peak) observed in some months of the year, primarily during the months (July-August-September) as a result of the summer vacation (high season), outside of these months, the normal low season. Furthermore, the seasons of religious visits shift from month to month due to the difference between the Gregorian and Hijri calendars.

7. CONCLUSIONS

In order to comprehend the dynamics behind the fluctuating demand at Baghdad International Airport, a model was created to simulate the demand patterns for the 10-year period from 2010 to 2019. The following is a summary of the major findings:

- The economic variables had a secondary impact that affected demand with a time delay, such as in GDP, where it took 24 months for a change in demand to become apparent.
- The exogenous variables, such as the country's political situation or the terrorist effect had the greatest influence on the main driver of demand,

which may be seen even after the impact has diminished.

- The social side, indicated by the size of the population of Iraq in the middle region, is continually growing, and this is reflected in the demand, which witnessed a growing trend in the total number of passengers over the study period.
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- The causal loop diagram illustrates the fundamental relationships that influence air travel demand; more than one negative feedback loop has an impact on airport activities. The increase in the number of passengers led to an accompanying rise in demand for flights, resulting in flight delay times and a decrease in the terminal utilization ratio.
- The fundamental model includes four accumulative stocks, flow rates, and auxiliary variables which produce two sub-models: departing and arriving passengers.
- The fluctuation is a phenomenon inherent to the global air transport industry. However, due to Iraq's unstable political and economic situation, external factors have a greater impact on the fluctuation of air travel demand, which causes demand shocks that take a long time to recover.
- The simulated result was very close to the real value, which shows that the model is reliable and can be applied.

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