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OPTIMISATION OF AIRPORT AIRSIDE OPERATIONS AND REDUCTION OF AIRCRAFT DELAYS

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Abstract

The demand for air transport has a rising tendency over the years. This leads to more and more aircraft movements at a given time. This increase may lead to traffic congestions and an increase in aircraft delays. Airports cannot expand indefinitely and therefore they need to look for other options to mitigate the congestions. The main objective of this paper is to increase airport airside efficiency and thus reduce aircraft delays at a chosen airport. Second chapter is dedicated to currently deployed solutions at airports and theories discussed among researchers which may help the cause. Fifth and sixth chapter focuses on airport airside efficiency at the Dubai International Airport. An in-house software solution for tracking ADS-B data is used for these needs. Output of this paper is an analysis of airport operations at the airport and recommendations are made to increase airport airside efficiency and reduction of aircraft delays.

Keywords

Airport airside efficiency, aircraft delays, AIXM, Dubai International Airport, information exchange models, ADS-B data, digital twin.

1. Introduction

It has always been a case that the aviation industry is being considered as one of the biggest technological pioneers in the world and it is very true from the point of view of the development of new technologies in aircraft as they seek to get them to the best point of operational efficiency, friendliness to the environment and safety alongside security. However, the opposite is true for the providers of air navigation services, or even the airports themselves. Airports have already gone through digitization, a process of converting analogue information into digital format, but many times they lack in the regard to digital transformation. Digital transformation aims to integrate more advanced digital solutions to already digitalized services, in order to achieve even better work efficiency. There are multiple solutions, which are being brought to the market and are being tried to be adapted by various aeronautical stakeholders. Aim of this paper is to bring a solution which tries to enhance airport airside efficiency. This leads us to the issue of AIXM and how its data is currently being used and what potential it has.

2. State of the Art

The aviation industry is characterised by long-term growth. It may not grow every day and rapidly, but more importantly it is steadily rising in the long term. Over the last couple of decades there have been particular setbacks which brought the aviation business to a halt, and it had to start over. However steadily over the years it regained its traction and got back on its feet which resulted in growth. The most recent notable event was the Covid-19 pandemic which caused a significant reduction of air travel, but nevertheless after just 2 years we saw flourishing numbers.

To accommodate these growing numbers of aircraft movements, new airports or additional infrastructure to existing airports have to be built if aviation industry wants to grow even more. Airport capacity constraints have a serious impact on the future development of air traffic and therefore capacity enhancements have to be made to mitigate the airport constraint due to the shear amount of air traffic as stated by **M. C. Gelhausen et al. (2013)** [1]. According to a study by **D. Lubig et al. (2021)**, a 10 % capacity increase at London Heathrow decreases inbound and outbound delay by 42 % and 80 %. Alongside air traffic congestions there also may be increased direct or indirect costs, such as increased operating, fuel, and maintenance costs for the airlines[2]. To allow greater amounts of traffic, airports have to expand in size. For an airport to handle the traffic congestions, expansions are inevitable [3]. However, everyone has their limits of some kind and airports are not an exception to the rule. Frequently, the place to do a physical expansion is not sufficient and airports cannot expand infinitely. It just may not be feasible to build new aprons with terminals or runways due to political, environmental, economic, and geological constraints as stated by **L. Yu-Hsin (2010)** [4]. In a study made by **M. Schrefl et al. (2022)** it has been recognized that it is important to advance technologically because automation is a possible solution to decreasing workloads and thus improving work efficiency [5]. Possibly the most famous concept solution is from EURONCONTROL. It is called “Airport Collaborative Decision-making” and works closely with the ATFCM network. It aims to improve the efficiency and resilience of the airport operations by optimising the use of resources and improving the predictability of air traffic. It is achieved by encouraging the airport stakeholders, such as airport operators, airlines, ground handlers and air traffic control alongside with the network manager to work more transparently and collaboratively, exchanging relevant accurate and timely information [6]. Other solution to reduce flight delays and optimise airside operations is by leveraging a so-called digital twin of an airport. Real-time alerts are possible when a vehicle or equipment is missing at an aircraft parking stand. This solution is deployed for example at Hong Kong Airport, and it improves operational efficiency by reducing aircraft turn-around time [7]. Alongside the systems used in the world, there are also scholars who try to address this topic of mitigating air traffic congestions. One of the whitepapers is a one by **H. F. Fernandes and C. Müller (2019).** They try to approach the problem of airside efficiency by creating a mathematical model which would allow to create the best way to sequence aircraft for departure and arrival. This problem may be mitigated by an appropriate sequencing of runway landing and take-off operations, thus increasing the efficiency of the whole airport. [8].

Tools and program are being proposed as a solution to better planning and coordination. **S. Chen et al. (2023)** in their paper created such a multi-agent planning and coordination tool for automated aircraft ground handling [9]. Research by **Ch. Stergianos et al. (2016)** has shown that the pushback process is pretty much interlined with aircraft delays that happen. When looking for the best sequencing order it is necessary to consider departing aircraft and the consequent blockage of an apron due to being pushed and while they start their engines [10]. Another paper published as a NASA report by **Ch. Bosson et al. (2015)** tries to achieve the same results as the study before. An algorithm was developed to be capable of computing optimal aircraft schedules and routing that reflect the integration of air and ground operations.

A study made by **J. Ma et al. (2019)** created a very complicated model at a macroscopic level which incorporated all of the knowledge we previously mentioned. This includes different airside components, aircraft speed, arrival and departure times, traffic sequencing and runway assignments. All of these aspects are factored in, and they are part of their computational experiments. The study was conducted at the Paris Charles De-Gaulle airport and one of the solutions applied, showed a decrease of 37 % of arrival delays and 36 % of departure delays, compared to the baseline case. They also concluded and confirmed that adjacent airspaces of airports, e.g. terminal manoeuvring areas, are the major bottlenecks of the air traffic management [11].

Literature review shows that scholars are mainly trying to address the problem by using mathematical algorithms, simulations and creating planning tools. They might work as a standalone solution but in order to fully achieve their potential, it is important for the tools to communicate with other systems used by the airport's departments. For example, if we take the A-CDM concept, multiple stakeholders are communicating between each other to exchange critical information. That is not possible, if each solution uses its own program language, which is unable to be de-coded by other airport department's programs. Therefore, it is wise, in order to advance forward, to use a standardized computer language, which enables communication between each solution.

2.1. Information Exchange Model

Just like as we humans exchange information, computers and their programs also need to exchange their data with each other. The integration of such model into our programs allows simpler electronic communication and faster exchange of data with each other. In practice, this means that a standardized computer language is created to exchange information that can be easily read by selected programs after the given language implementation. Several such standardised models exist. This paper focuses on one of them called the Aeronautical Information Exchange Model (AIXM). it was meant to be used by the European AIS Database project by EUROCONTROL, but nowadays it has evolved into a computer language for the encoding and the distribution of digital aeronautical data used globally [12].

2.2. AIXM

AIXM provides an Extensible Markup Language (XML) schema that enables the coding of the aeronautical information that needs to be collected, managed, and provided by the Aeronautical Information Services (AIS). AIXM supports 4 basic data sets used by the AIS. It comprises of Aeronautical Information Publication, Instrument Flight Procedures, Obstacle and Airport Mapping data sets [12]. The system enables encoding of all parts of AIP and thus including its whole content in the 3 main sections - general, en-route, and aerodromes [13, 14]. And while the main usage of AIXM is in civilian operations, it has also practical use-case in military operations. A case study made by **R. Jardim et al. (2022)** showed the possibility of AIXM being used in them. The Brazilian army currently uses AIXM for storing geographic information and shares it with other Brazilian military branches. [15].

2.2.1. Digital Data Sets

A data set is data organized into a type of a structure. It is important to note that a data feature may appear in multiple data sets at once. For the purposes of increasing airport airside efficiency, we take a closer look at the Aerodrome Mapping Database (AMDB) and its applicability [16].

2.2.2. Aerodrome Mapping Database

The first step for creation of a digital database is to gather all available data for the purpose of compiling. After we successfully perform that, we organize and arrange the data into a database. AMDB supports requirements for collaborative decision making, common situational awareness and aerodrome guidance solutions in the following air navigation applications: position and route awareness including moving maps with own ship position, surface navigation, traffic awareness including surveillance and runway incursion detection with alerting service [14, 17].

2.3. The Use of AIXM in Air Transport Research

As AIXM just started being more widely used in the recent years, there are not many papers who explore the possibilities with AIXM. Nevertheless, couple of them exist and they do showcase the applicability of AIXM in the real world and how it can achieve better airside efficiency.

A study made by **S. Egami et al. (2020)** showed the possibility of building ontologies based upon various exchange models, which enhance operational efficiency. The aviation industry is always expanding and so are the numbers of air traffic movements. AIXM supports the creation of systems which improve the safety and efficiency of aircraft operations. Not only these systems allow for the better handling of those traffic numbers but also allow increasing them by enabling cross-department information exchange [18]. The recent moves into the direction of global information standardization within the aviation industry has triggered an increased demand for aviation data to be readily available, accurate and easy for each party to use. Paper by **W. Rahayu et al. (2012)** states that system used in aviation are mainly old proprietary disparate systems so there is a growing need for a system which could act as a collaborative decision support system, where the right data can be used at the right time and by the right users. AIXM is the core standard model for data transmission and format conversion [19]. The **B. Ren and Y. Jiang (2021)** study explains that the extensibility of the data exchange model can be used to expand the corresponding data structure even more according to the characteristic of different national air traffic control systems and special business rules requirements [38]. A case study was done by **C. Morales and S. Moral (2016)** with the aim of modelling aircrew information management for estimation of situational awareness. Standards such as AIXM, will probably be widely implemented into electronic flight bags (EFBs) in the future [20]. Research on application modelling and visualization based on aviation information exchanged model was done by **X. Lai and J. Hu (2020)**. AIXM defines various aviation features which can be come across during the whole duration of a flight. These features can create a spatial simulation using computer visualization technology based on AIXM and therefore help flight operators, control personnel and other aviation entities to establish a better situational awareness and improve the flight safety [21]. The drone industry is also growing, even amongst the general public. **L. Xin et al. (2024)** case study created a helicopter path planning method based on AIXM obstacle dataset. It was used as the main source of aeronautical data in the aeronautical information exchange network and designed a method of AIXM structured obstacle data. This resulted in a reduction of the numbers of helicopter turns and ensured the safe distance between the flight path and the obstacles. Even though it was used for flight planning it is safe to assume it could be expanded to real-time operations and decision making. This same approach could be implemented into drones or other autonomous aeroplanes and increase airport airside efficiency [22].

Literature review suggests that the main point of the studies is to introduce AIXM and its use-cases. Between the scholars, it is widely agreed that AIXM provides a mean of enhancing air operations without evident drawbacks. Therefore, this paper takes advantage of the flexibility of AIXM data and brings a practical solution to enhancing airport airside operations. In the recent years, airport planners started to use simulations to predict traffic at their airports to anticipate better evolving traffic at their current taxi layouts. **M. Sabic et al. (2021)** created a model that includes an airport and airspace simulation software in conjunction with prediction models [23]. One exemplary use case was showcased by **K. Dönmez et al. (2022)** where they ran a simulation on the Samsun Çarşamba Airport in Turkey with a proposed taxiway system and found out it can significantly reduce airborne delays, departure queue delays and runway occupation times compared to a backtrack system [24]. This is where our paper steps in and uses the flexibility of AIXM data to change the layout of an airport's digital-twin and simulations are run to find better solutions for the optimization of airport airside efficiency.

3. Scope, Purpose, Objectives

Scope of this paper is twofold. It focuses on the optimization of airside efficiency and in addition, it focuses on the use and exchange of aeronautical data and its application in the airport airside operations. Second chapter is dedicated to solutions how the reduction of aircraft delays is accomplished. It describes mathematical algorithms and formulas, which enable to sequence airplanes in such way that the airport's traffic output is at its maximum. One of the objectives of this paper is to bring awareness about the problems caused by air traffic congestions at various levels and how they are all connected. Additional objective is to find a solution to optimize airport airside efficiency and consequently reduce aircraft delays at a chosen airport. In this paper AIXM data of a digital twin airport are utilized. In the second step a simulation is used at the airport of our choice. According to the simulation, two key performance indicators (KPIs) are looked at. The first one is taxi time and the second KPI is fuel consumption of a given aircraft. The main limitation of this paper is how the data for KPIs are obtained. It relies on publicly available ADS-B data, which can be missing at ground level. This may lead to not-so-true accurate data. The reason why we chose to explore the taxiway re-design possibilities with AIXM is because during our literature review, we did not come across any papers trying to achieve our goal by proposing similar steps. With a help of an in-house software, it is possible to change taxiway layouts very quickly, because AIXM data is very flexible.

4. Research Methodology

The research part of this paper is an analysis and made in conjunction with a business company, who is able to provide their in-house software to utilize AIXM data for airport airside simulations. Simulations are run at the airport and allow us to analyse current airside operations at it. This is quantitative research, where we obtain exact and objectively verifiable data. Based on observations seen in our KPIs, results are presented. They form a baseline from which we try to find a solution to optimize airport airside efficiency. We try to achieve the goal by re-designing current taxiway layout at our chosen airport by creating, relocating, or removing taxiways. In chapter 6 we use comparative methodology and compare these new KPIs to the old ones. A conclusion is made, whether the optimization of airport airside efficiency with the consequent aircraft delay reduction was achieved or was not.

5. Current Airside Operations and Aircraft Delays at a Chosen Airport

We have decided to explore the possibilities of enhancing operational airside efficiency at Dubai Airport. It is an airport which has multiple active aircraft movements in a given moment and has already a quite extensive taxiway infrastructure.

5.1. Dubai International Airport

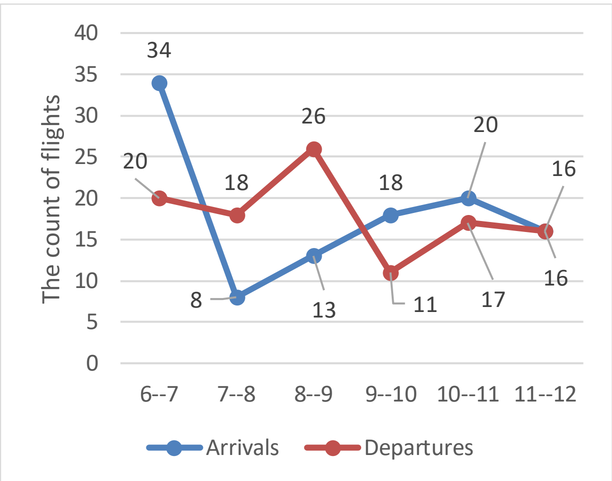
Dubai has two main runways which are parallel to each other. Runway 12L and 12R, runway 30L and 30R. The runways are separated by taxiway M, which follows alongside the whole length of the RWY systems. The airport could be divided into three main segments. The first, northern segment, has Terminal 2 with Apron E. The second, middle segment, is located between the two runways and mainly consists of the taxiway M. It is used as a connection between the RWY ends and ATCOs sequence departing traffic on it. In a case of a wind from the SW to NE in a clockwise direction, Dubai uses runway 30L as the main landing runway and runway 30R as the main runway for departures. In a case of a opposite wind from the SW to NE in an anti-clockwise direction, then the main runway for landings is 12L and for departures runway 12R. This rule also applies in low-visibility operations. The third, southern segment, covers Terminal 1 and Terminal 3.

5.2. Simulation Tool

The team at "NG Aviation" has provided us with a simulation tool, called "NG-AviaSIM" which can observe live ADS-B traffic and record the data for future reference. It is an in-house software solution developed by them. It utilizes AIXM 5.1 data for visualisation and information access in 2D and 3D view. The live ADS-B data are recalculated in post-processing after the ground movement of an aircraft has finished. This process allows the calculation of multiple possible KPIs. These include taxi times, fuel consumption, average thrust levels and emissions produced (CO, HC, NOx). In order to find out KPIs of specific taxi routes, manually created simulations can be used. All other flights which are being simulated, are displayed to the user in the Preview mode. It also supports conflict detection. When a collision is detected, the user is notified, and he must make a manual change to the flight - adjusting the taxi route or defining a holding position on the route.

5.3. Airside Operations

For our purpose, live ADS-B data was recorded for Dubai Airport. We decided on morning traffic starting from 6 o'clock until 12 o'clock. The following ADS-B data was recorded during the morning of the 18th of April 2024. In total 217 aircraft movements were made in the 6-hour morning window. In the following graph, we see the traffic evolution for every hour. Out of the six hours, we have chosen a time period when peak traffic was experienced. On this date, it was experienced between 06 and 09 o'clock in the morning.



Graph 1. Traffic evolution at Dubai Airport on the 18th of April '24. Source: [NG-AviaSIM]

5.3.1. Arrivals

In total 55 aircraft movements were recorded. Average taxi-in time was 3 minutes and 11 seconds. In fact, half of the flights were shorter than 1 minute and 32 seconds. These numbers are quite impressive for an airport of such extent. However, during a close examination of the gathered data we find out that they are incomplete. This is the shortcoming of this paper. This is caused by the nature how the simulation tool obtains ADS-B data. It uses publicly available data on internet sites to download them in real time. These ADS-B data providers rely on community-made ADS-B capable antennas and receivers. Many times, these are mounted in not so suitable locations to be able to continuously capture all the ground movements at an airport reliably. Once the signal is lost, the simulation tool stops recording the data and ends the flight, even though the flight re-appears minutes later at a different position. However, all arrival simulations may be manually re-generated, with their full real life taxi routes. This comes at a great cost, because the manual simulation cannot replicate position holds, taxi speeds, and other operational restrictions of the real flight which were encountered during the live ADS-B data simulation. This means, that all values are going to be the most ideal case, where the flight reaches its gate in the shortest possible time without restrictions. In other words, the manual simulations are at a theoretical level, of what the airport and aircraft are able to achieve together.

As a showcase we use flight EK184. According to the raw data of the simulation tool the taxi time of the flight was 6 minutes and 37 seconds. In the case of this flight EK184, no adjustments were needed to the taxi route. However, it serves as a prime example how the re-generated simulation does not consider the real taxi speeds and other factors. In the re-generated simulation of the flight, we see a taxi time of 5 minutes and 22 seconds. And as we have noted earlier, compared to the real live ADS-B taxi time, this re-generated taxi time is well over a minute faster. Therefore, all simulations from now on are going to be in ideal conditions. In the table below, we have average taxi time and total fuel consumption.

Table 1. Re-generated KPIs for arrival flights. Source: [NG-AviaSIM]

Arrivals (36 flights)	
Avg. taxi-in time (mm:ss)	*07:50*
Median of taxi-in time (mm:ss)	*08:30*
Fuel consumption (kg)	*16 386*

5.3.2. Departures

As for departures the average taxi-out time, on a sample of 64 flights, was 16 mins and 42 sec. Median was just 2 seconds shorter. These numbers are quite believable and may depict the real traffic at the airport. However, arrivals and departures at an airport cannot be separated. Arrivals influence departures, and departures influence arrivals. It is a never-ending loop, which cannot be broken during live operations. Therefore, departures must be also manually re-generated, like it is the case with arrivals. This brings both of them on the same theoretical level, where we can see ideal operations without interruptions. We have re-generated all of the ADS-B traffic that we were able to.

Table 2. Re-generated KPIs for departure flights. Source: [NG-AviaSIM]

Departures (48 flights)	
Avg. taxi-in time (mm:ss)	*07:39*
Median of taxi-in time (mm:ss)	*07:48*
Fuel consumption (kg)	*18 029*

The total number of departures we work with is 48. The average taxi-out time is very similar to arrival's taxi-in, with a negligible difference of 10 seconds. However, the median is way lower compared to the arrivals and around 42 seconds less. In the table below we have a direct comparison between arrivals and departures after the re-generated simulations.

Table 3. Comparison of ARR and DEP KPIs. Source: [NG-AviaSIM]

Departures (84 flights)	***ARR***	***DEP***
Avg. taxi-in time (mm:ss)	*07:50*	*07:39*
Median of taxi-in time (mm:ss)	*08:30*	*07:48*
Fuel consumption (kg)	*16 386*	*18 029*

5.3.3. Arrival and Departure Flows

During our recording session of live ADS-B data, there was a north-westerly wind, which caused the airport to adapt the runway 30L as the main landing one, and runway 30R as the main one for take-offs. Dubai Airport does not have published standard taxi routes in the UAE AIP. This opened the question, what are standard procedures for taxiing and sequencing of aircraft.

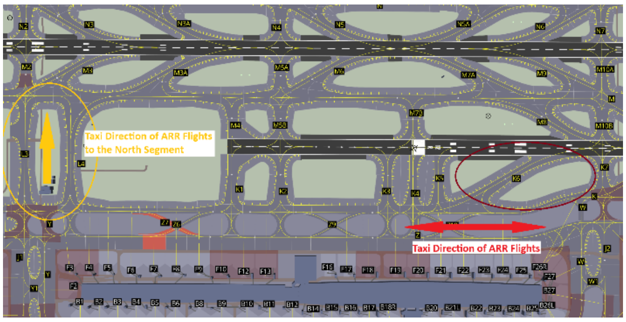


Figure 1. Standard arrival taxi flows during runway configuration of 30L and 30R. Source: edited by author [NG-AviaSIM]

Almost all of the arrivals did utilise rapid exit taxiways (RETs) to the left of the landing runway 30L. As they vacated the runway, for instance by using RET K6 (burgundy ellipsoid in figure 17), they joined main taxiways alongside the third segment of the airport, as depicted by red arrows in the figure. If flights wanted to get to the first segment, they joined taxiways L3 and L4, as depicted by the orange circle and arrow. In this runway configuration, flights to segment 1 of the airport, have a long non-direct taxi route. These flights were not always taking advantage of the RETs, to the right of the landing runway, which would mean shorter distances. As for departures, ATCOs were sequencing traffic from the third segment of the airport by using taxiway L3, L4 and taxiway M, which is in between the two runways. This is the reason, why perhaps the landing aircraft on runway 30L do not always take RETs to the right. Aircraft taxiing for departures would end up head on with the landing aircraft.

6. Modelling of Solutions for Optimised Airside Operations and Reduced Aircraft Delays at a Chosen Airport

Dubai airport has a mature and extensive network of taxiways. If there is a room for improvement, then it is going to be a very small one. Both of the runways have multiple rapid exit taxiways at the recommended distances from runway thresholds by ICAO's Aerodrome Design Manual to accommodate the most traffic [48]. Taxiways are everywhere and they are all connected in multiple ways with each other. After careful consideration, we have decided to explore a possibility of enhancing airport airside efficiency by adding a perpendicular taxiway to runway 12L/30R.

6.1. Proposal With a Perpendicular Taxiway to RWY 30L

It would be located at the halfway mark of the runway, thus connecting taxiway M and N together. This could allow one more direct connection between these two taxiways. Observations of live ADS-B data in NG-AviaSIM showed us that, when runways 30L and 30R are in use and after landing on 30L, RETs to the right are rarely used. This can be due to the fact that they lead onto taxiway M, which is primary taxiway for sequencing departing aircraft. However, if operations permit and no aircraft are taxiing on M for departure, then ATCO's may use it to create a shortcut to northern part of the airport. In fact, we were able to observe two flights, which used this shortcut, when they wanted to get to the northern part of the airport.

NG Aviation has provided us with another tool called "NG AIME Data Creator". It is a tool that is used for the creation of AIXM data. In our case it allows us to easily create the new proposed taxiway. In the figure below we see a snippet of how the new taxiway was made. It is highlighted by the green outline.

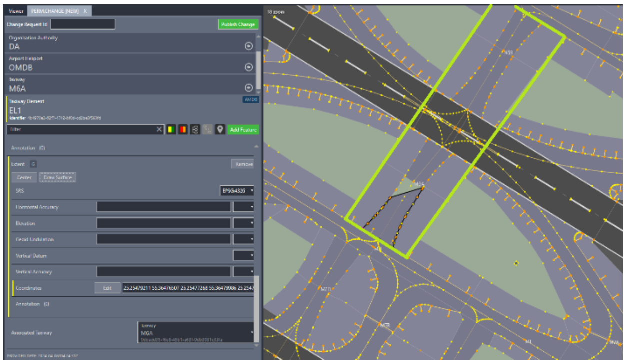


Figure 2. Design of a fictional taxiway M6A. Source: edited by author [NG AIME Data Creator]

After the data creation process, the new repository is uploaded into the NG-AviaSIM tool, and the airport is correspondently updated. The following figure showcases what the final output looks like.

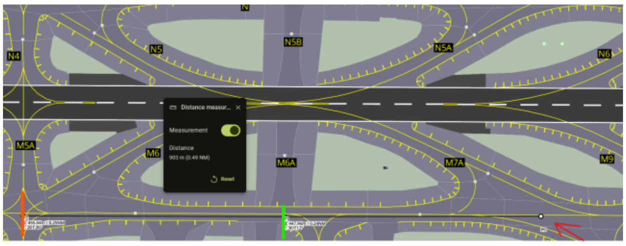


Figure 3. Proposed new taxiways and their distance to RET M8. Source: edited by author [NG-AviaSIM]

This proposed change halves the distance, of the next possible turn to the right to get onto taxiway N, after an airplane has vacated runway 30L via RET M8 (indicated by red arrow). The old distance was approximately 900 metres (orange line) and now it is only 450 metres (green line) as seen in the illustration above. An if an airplane vacates via M11 as mentioned earlier, then the distance reduced from 1 300 metres to 830 metres. Therefore, this allows a bigger margin for ATCOs to work with in order to allow airplanes to use the RETs located to the right after landing and shortening the taxi routes.

In the end we use the simulation once again to re-generate existing flights that can utilize the new taxiways. In total, there were 5 arrivals out of the 36, that could use the new taxiways while respecting the outbound flow. In the next table, we compare old and new KPIs of all traffic together at the airport.

Table 4. KPIs comparison of all ARR and DEP traffic together. Source: [NG-AviaSIM]

KPIs	*Old values*	*The difference*	*New values*
Avg. taxi time (mm:ss)	*07:44*	*-00:12*	*07:32*
Median of taxi time (mm:ss)	*08:04*	*-00:32*	*07:32*
Fuel consumption (kg)	*34 415*	*-453*	*33 962*

7. Conclusions

In theory we have optimised the traffic situation of Dubai Airport's airside operations with this solution. We have met our goal of improving airport airside efficiency and reduction of aircraft delays. We achieved this by shortening taxi-in for arrival and aircraft. Average taxi time was reduced by 12 seconds, which is an improvement by 2,5 %. The median was reduced by 32 seconds, which corresponds to an improvement of 6,6 %. On the other hand, we have not seen a big reduction in total fuel consumed. The 453 kilograms of fuel saved equals to an improvement of 1,3 %. However, over a longer period of operations, even the smaller percentage may create a significant difference.

In theory, it is faster and ATCOs have more options to route traffic. However, this reduction is only possible if ATCOs are more precise with their sequencing and timing. And moreover, the solution could be used only if the traffic situation permits. It all comes down to the airport management if the proposed solution and its cost is worth the saved time and fuel.

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