Airport Layout Planning

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Abstract

Airport layout planning is a highly complex discipline which requires much forethought, as inadequate or suboptimal solutions could be both dangerous and costly. However, designing a good airport requires compromises between the requirements of all stakeholders involved, ranging from aviation authorities and airlines to passengers and nearby residents. This is a highly delicate issue as evidenced by current airport extension proposals in the UK, including Heathrow and Stansted airports. Although airport planning tools exist, no tool presently allows multiple stakeholders to observe and interact with a single airport planning model, allowing them to evaluate a proposed layout from different points of view. This paper aims to illustrate the applicability of Empirical Modelling concepts to such a process, by constructing and demonstrating the use of an airport model.

1 Introduction

1.1 Overview

Airport planning is a complex, time-consuming and highly costly process. Countless rules, regulations and physical restrictions govern the placement of essential components culminating a complete airport, such as runways, taxiways and passenger terminals, to name a few. Inadequate or suboptimal placement of structures can be extremely costly and in some cases, potentially hazardous. Governing bodies such as the UK's CAA[1] are responsible for issuing and ensuring adherence to strict guidelines to ensure airport safety, security, economy, efficiency and longevity.

Given the ever increasing volumes of both passenger as well as cargo transport, airports are virtually continually expanding. In 1970 the UK handled 32 million passengers through all its airports; a figure which increased to 180 million by 2000 and is forecast to reach 275 million by 2010 [2]. The astronomical increase in demand for air travel has resulted in rapid airport growth. Unfortunately resources such as space are often limited, thus amplifying any possible ramifications of new airport construction or existing airport expansion. Over the years, computer simulation tools have been used for a wide variety of applications, ranging from nuclear reactor to road traffic network simulation. Airport layout planning is no exception and a myriad of tools have been developed to aid airport planners in designing new or expanding existing airports. Products such as those offered by *TransSolutions*[3] and *Airport Research Center GmbH*[4] allow planners to model airports prior to construction, in order to evaluate factors ranging from movement of terminal passengers to movement of airfield traffic. These tools provide accurate dimensions and measurements for airport designers, as well as using mathematical techniques to model aspects such as passenger flow through terminal buildings. Such simulations help mitigate inadequate planning prior to actual construction and have proven useful within predefined scope.

Designing something as complex as a modern airport is not a trivial task, as a multitude of stakeholders must be taken into consideration. A design plan that constitutes a *good* airport can be seen as a set of compromises between all stakeholders, which can include any persons or organisations such as the CAA, the government, airport owners, airport workers, airlines, passengers and residents living nearby. In some cases, stakeholders' goals coincide, while in other cases they might conflict. More importantly, it must be recognised that stakeholders view any proposed solution from entirely different points of view. For example, the CAA might require that departing aircraft on a taxiway maintain a minimum separation distance of $200m$ while airport owners might want to maximise the potential passenger throughput. On different but nonetheless valid notes, passengers might want minimal queues once inside the terminal building, while nearby airport residents might want minimal visual impact of the airport on the surrounding

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[1] Civil Aviation Authority
[2] Figures taken from `http://www.cpe.org.uk`

[3] `http://www.transsolutions.com/`
[4] `http://airport-consultants.com/`

environment. A present example is the recent expansion of London's Heathrow Airport to include a fifth terminal, with ongoing discussions between stakeholders for the construction of a third runway.

It was previously stated that existing simulation tools have proven highly effective tools for airport planning. What they do not provide however is, for any given aspect, a tool able to cater for the perspectives of all the model stakeholders. As a result, while not necessarily a full replacement for traditional simulation approaches, Empirical Modelling (EM) has much to offer in terms of airport planning. By constructing and maintaining dependencies between airport components, a significant portion of the layout design process is automated on behalf of the user. Such an example might be the requirement of a fire service station to be present within half a mile of any given point on a runway, or for every runway to include a runoff at least a certain percentage of the runway's length. EM would allow designers to perform simulations in virtual environments which would otherwise be impossible. As outlined in Beynon (2005), interaction with an environment representing a real-life environment constructed based upon observation, allows users to mimic potential real life situations. Safety concerns regarding minimum run-off, approach visibility, maximum aircraft wingspan and permissible runway payload, runway lighting, runway dimensions and separation distances are all restrictions which EM easily allows to be taken into account. Such a model could also allow potential passengers to ensure accessibility or washroom facilities are always within easy access within any part of the terminal building, or nearby residents to evaluate different airfield layouts such as to minimise noise or visual impact.

1.2 Objectives

The primary objective of this project is to demonstrate proof of concept for the application of EM to airport layout planning by constructing and demonstrating an empirical airport model. The scope of this is to develop a tool which could theoretically allow multiple stakeholders to view and interact with a single model in order to achieve different goals. The implementation of an airport planning model could be restricted to *2-D* or *3-D* visualisation, or simulation of airport interaction. Since the extent of such a project's possibilities is extremely diverse and due to time constraints, this study shall be limited to a high-level placement of primary airport buildings and

Stakeholder	Requirements
CAA*	Enforce safety regulations
Government*	Enforce security regulations
Airport Owners*	Maximise passenger throughput
Airlines*	Maximise passenger turnover
Passengers	Minimise queueing
Airport Staff	Ensure facility / accessibility
Nearby Residents	Minimise noise / visual impact

Table 1: Airport stakeholders

components in *2-D* only.

2 Empirical Modelling

2.1 Real-World Application

One of the greatest strengths of EM is the ability to construct open, experimental and experiential interactive environments. EM tools allow for the construction of models of real-world environments by observation. This is especially useful in situations where domain knowledge is incomplete, giving rise to a pre-theory experimentation approach, simply by modelling state. With regards to airport layout planning, a model can be created to represent the various components that constitute an airport. This process is based on experimental observations, as outlined in Beynon and Cartwright (1990), albeit the agents' abilities within the model shall not be restricted depending on their perspective in the design process. However, the power of the model is its ability to provide a human computing interface in order to allow for the design of a *good* airport. But how can this be achieved?

EM provides the ability to model a situation or environment with different motivations. Table 1 provides a list of airport stakeholders, each of which observes different aspects of and has different expectations of a potential airport. All are different but all are equally relevant and important. To create a suitable model, each of these aspects must be properly modelled in a definitive script. A given definitive script can be categorically analysed given three different aspects; *observables*, *dependency* and *agency*.

2.1.1 Observables

Observables are entities whose state can be captured by experiment. In the case of airport planning,

the observables shall be the various airport components, including runways, taxiways, terminal buildings, amongst others. An airport must consist of a minimum set of these buildings for core functionality. As an airport expands, different buildings may be added as required. Implemented observables are restricted only by the model granularity and as such may represent something as broad as a runway or as specific as an individual sign inside a terminal building.

2.1.2 Dependency

Dependency defines the relationship and constraints that must be maintained between observables. The list of dependencies in an airport is largely governed by restrictions and guidelines outlined by organisations such as the CAA. These relationships might be the mandatory presence of firefighting facilities within $50m$ of any building or to have separate bathroom facilities for every $1,000$ people inside a terminal building.

2.1.3 Agency

An agent is anything that can change the current state of any of the entities or observables within the model. The predominant agents within the airport layout planning model shall be the modellers, or the stakeholders of the model as outlined in Table 1.

The aim of this project is to develop a script of definitions in an attempt to capture the interests of stakeholders and represent them in a relevant and consistent model environment, through which an action or requirement of one may be immediately interpreted and understood from all other points of view. Given that the scope of this model shall be limited to certain building types, the model shall only be applicable to the stakeholders marked * in Table 1.

2.2 Existing Tools

EM is a relatively new field of study and thus the available tools are still somewhat limited. The primary tool currently available is `tkeden`; an interpreter supporting the use of a range of definitive notations, each of which providing different abilities. Without delving into further detail, the chosen notation for the airport planning model shall require the combined use of `EDEN`, `DoNaLD` and `SCOUT`, using similar principles as defined in Beynon and Yang (1990).

2.2.1 EDEN

`EDEN` can be used to generate a definitive script to monitor certain aspects of the model being developed. `EDEN` shall be used to check and control constraints that must be observed between various airport building parameters, including size and placement. This is required to trigger certain types of messages as parameters are changed while running the model.

2.2.2 DoNaLD

`DoNaLD` is a definitive notation for *2-D* line drawing. `DoNaLD` allows for the construction of models consisting of simple points and shapes which shall suffice for the visual representation of an airport. The power of `DoNaLD` allows definitive shapes to have their dimensions and locations defined in relative, rather than absolute terms. In the context of the airport planning tool, components are able to be defined in terms of each other, thus providing a dynamic feel to the model as parameters are modified.

2.2.3 SCOUT

Lastly, `SCOUT` will allow for the construction of a definitive notation defining screen layout. Rather than forcing a user to enter instructions and alterations to the `DoNaLD` script manually, `SCOUT` shall provide a view port window to the airport drawn using `DoNaLD` and accompanying controls in order to alter the placement of the airport components. `SCOUT` shall also be used for displaying of error messages as and when `EDEN` detects airport constraint infringements.

Unfortunately, much of the tools currently available are incomplete and poorly documented. The development environments are often difficult to use and error messages are often cryptic and difficult to isolate. The tools are also somewhat unstable, with some issues appearing to occur non-deterministically making them difficult to reproduce. Furthermore, interfacing between various definitive notations including accessing variables is largely inconsistent. Accessing properties for example from `eden` to `DoNaLD` is different to accessing data *vice versa*, which is also the case with other definitive notation environments. This makes it extremely awkward to develop models with ease, making model development a highly time consuming process. However, despite the availability of alternative tools, `eden`, `DoNaLD` and `SCOUT` shall suffice for the construction of the simple airport model.

3 Model Design

3.1 Overview

Presently there are several commercially available tools for airport planning purposes. The majority of these tools tend to work in isolation, and are restricted to modelling terminal buildings, taxiways or runways alone. These tools are highly effective, but have a single common failure in their inability to model state and generate an experience in a wider sense, to achieve the goals of all stakeholders involved. This section outlines the scope and implementation of the empirical airport model.

3.2 Scope

The scope of the model to be developed is to set up the dependencies between major components that make up an airport, amongst others, this shall include runways, taxiways, terminals, hangars and fuel depots. The objectives of the model shall be to allow for dynamic allocation of all airport components in such a manner so as to satisfy the requirements of the stakeholders involved. The model shall begin with a simple airport layout. The user should be free to move around any airport components on screen. However, doing so might result in other components being moved depending on model constraints and dependencies.

3.3 Implementation

The model shall consist of a screen which will dynamically resize its contents depending on the size of the window, based on techniques outlined in Beynon (2007). When being viewed, the top 75% of the window is used as a view port viewing area; a top-down view of the entire airport being designed. By default, a certain set of airport components are present, however these can be added or removed as required. In the lower portion of the screen there shall be controls to enable the user to move components around the airport dynamically. The controls also allow the user to resize components such as runways. Whenever any action is taken, all components reaffirm their adherence to CAA standards depending on size and location. The next section is a list of airport components and interdependencies that are ensured by the model. While this list is non-exhaustive in terms of all possible airport buildings, it is sufficient for the purposes of this model. Furthermore, quantitative requirement values are chosen arbitrarily. Should the user decide to modify any of the airport's building parameters,

they too will be subject to guidelines and dependencies which will inform the user if something illegal, dangerous or simply not possible is being implied. The model itself consists of separate `airport.d`, `events.e` and `screen.s` script files for the various notation types, with a single `eden` script file `run.e` to initialise all definitive scripts.

3.3.1 Runway

The runway is the most obvious and recognisable airport component. The implemented model contains two runways by default. The most basic requirements for a runway are length, width and runoff area. A runway's approach system consists of:

- **ILS**[5]: Localiser (horizontal) and glidescope (vertical) must be present in the form of an end-of-runway transmitter.

- **Outer, Middle & Inner Marker beacons**: Flashing lights to help pilots to judge distance.

- **Runway approach lighting**: Used to illuminate final approach for landing aircraft. These can be summarised as REIL[6] (white strobes lights at end of active runway) and HIRL[7] (white lights at side of runway and red/green end lights indicating the end/start of runway).

3.3.2 Runway Designator Board/Lights

Board showing runway ahead (i.e. 'Runway 09R-27L' with red lights to show non-active runway and yellow for an active runway). This is important for pilots not used to an airport while clearing for take-off. This is particularly important as accidents have previously occurred due to the lack of such indicators, such as the Singapore Airlines accident while taking off from a Taiwan airport in 2000. Tarmac markings are also a critical part of on-ground navigation, including hold-short lines. On taxiways joining runways and crossing other taxiways there are hold-short lines used as marker points, or to give way to other aircraft.

3.3.3 Terminal Building

The terminal building is modelled as a single unit representing all passenger throughput, ranging from baggage check in and gate boarding to arrivals and

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[5]Instrument Landing System
[6]Runway End Identifier Lights
[7]High Intensity Runway Lights

baggage retrieval. The terminal building is also coupled with aircraft docking bays (gates), initially set to be identical in size, used as aircraft parking bays for loading and unloading. The terminal building must be located within an area with easy access to passengers arriving and departing from the airport, as well as easy access to the airfield for aircraft docking. It must also contain adequate building evacuation locations and emergency exit locations.

3.3.4   Gates

Gates are typically $80m \times 80m$ designated areas sufficiently large to park any commercial aircraft. A gate must consist of an air bridge for passenger boarding, fuel hose attachments, marker lines for parking and other facilities required by an aircraft for unloading or takeoff preparation.

3.3.5   Fire Station

The fire station is a legally required aircraft component that must be within easy access of any constantly used section of the airfield, in particular the runways and adjacent to the passenger terminal building.

3.3.6   Weighbridge

A weighbridge is used to weigh aircraft before takeoff if load sheet values are unsatisfactory, as well as to check below maximum permissible takeoff weight. A weighbridge must therefore be stationed adjacent or en-route to the start of a runway, prior to takeoff.

3.3.7   Windsock

Despite modern advances in weather radar and other weather monitoring systems, a windsock is still highly important for the pilot to check speed and gusting of the wind prior to takeoff. Windsock requirements are relatively simple; a tough, brightly coloured canvas sock measuring approximately $2m$ long and suspended off a pole $5m$ into the air. These requirements cannot be reflected in our simple model, however the fact that windsock must be visible at the start (takeoff point) of any given runway, can be modelled.

3.3.8   Jet Blast Deflectors

Jet blast deflectors are not used everywhere but are usually seen in larger airports. These deflectors are used to stop large amounts of thrust from taxiing aircraft from damaging other structures, and as a result

are only required towards the start of a runway and/or between taxiways adjacent to buildings.

3.3.9   Control Tower & Radar

The control tower houses approach controllers and ground controllers. It is imperative that the control tower is in a clearly visible location in full view over the airport and runways for ground controllers. Although this is often accompanied by an additional 'ground' tower to aid visibility, the model shall only cater for a main control tower. In addition to the control tower, a radar is also required for long distance visibility as well as short distance visibility in poor condition scenarios.

3.3.10   Fuel Depot

A fuel depot is the main fuel store for all aircraft refuelling. Although it must be within easy access, a fuel depot must have a clear $250m$ radius to avoid unnecessary damage to buildings in the immediate vicinity in the event of an explosion.

Before proceeding any further, a clear distinction must be made between model dependencies and constraints. Dependencies are aspects of a model which represent relationships between various components. Constraints are physical or environmental restrictions governing the interaction of the airport components, as outlined in Adzhiev et al. (1990). To represent these aspects, a series of Boolean variables shall be present which will monitor changes in the model's state in real time. As the state of any variable changes, the user will immediately be notified on screen by means of error messages displayed using SCOUT.

4   Results

4.1   Evaluation

The model was tested using several parameters and many changes were made to the environment state. Figure 1 illustrates a screenshot of alternate airport layout planning models in operation. The developed airport model successfully provides a visualisation of a conceptual representation coupled with functional dependencies, in a similar manner to that in Beynon et al. (1990). Moving components such as the Fuel Depot, Control Tower, Runway, Weigh-Bridge or Fire Station around all yield potential user warnings. The constructed model is very simple in nature,
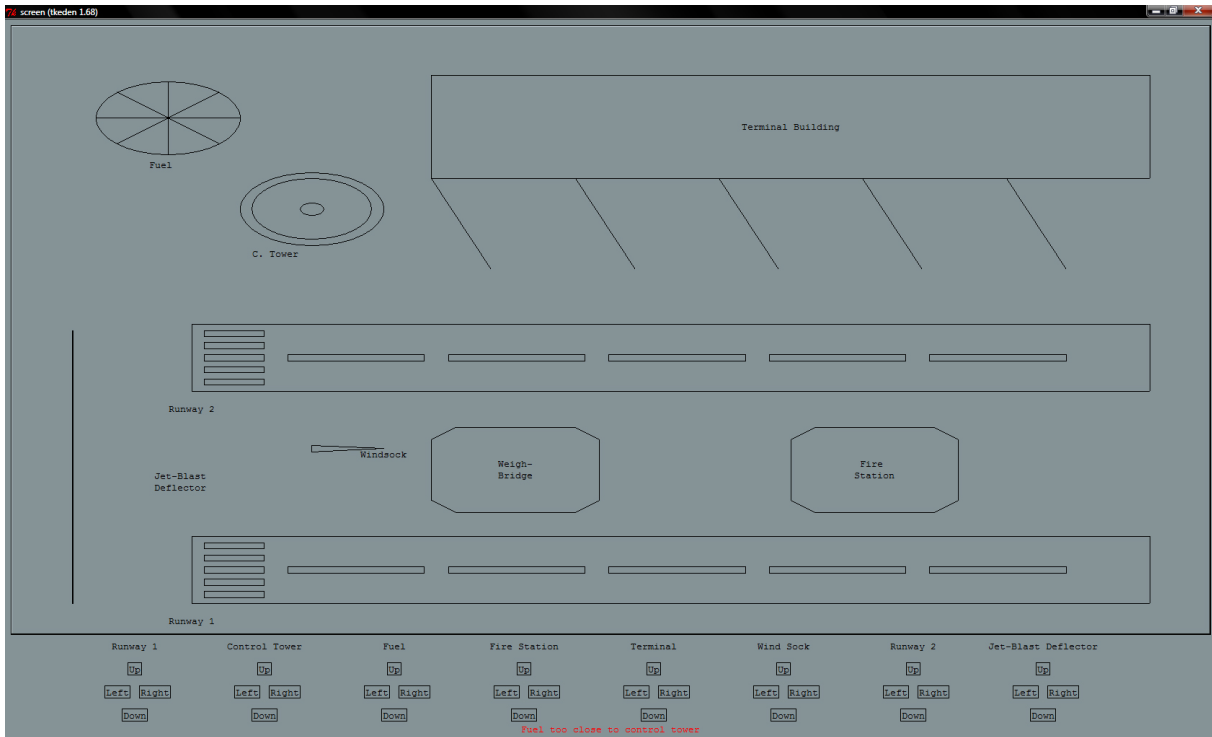
Figure 1: Screenshot of model in `tkeden`, using `eden`, `DoNaLD` and `SCOUT`

and in terms of possible visual control functionality for all possibilities concerning the displayed airport components is not exhaustive. However, the implemented functionality is sufficient for proof of concept that EM has the potential to contribute towards airport planning and development.

5 Conclusion

5.1 Critical Summary

Through a relatively simple model it has been shown that it is feasible and realistic to create an airport planning tool. Although the model only reflected the high level placement of common airport components, it can clearly be seen that EM concepts are readily applicable and useful for airport planning. By allowing multiple stakeholders to partake in the design and planning of an airport, such a model is able to evaluate multiple aspects from different points of view on a single model simultaneously. The tools `eden`, `DoNaLD` and `SCOUT` successfully provided a suitable framework within which such a model could be developed.

5.2 Future Work

The scope of this project was to provide proof of concept that EM does have valid, real-world applications to airport planning. As a result, the implemented model was a relatively simple one and there are several additions and improvements to the model that could be implemented. The first of these improvements could be the potential representation of non-visible aspects of an airport, to increase the model's scope to encompass more stakeholders. This could be done by the representation of line-of-sight and audible distance ranges to evaluate the impact on people living nearby the airport. Another interesting addition would be the analysis of the airport under reduced visibility conditions, thus necessitating the placement of adequate lighting. Other basic improvements could be to allow for the rotation of components in 360°.

Additional airport restrictions that could be added include the addition of noise abatement zones; points at which aircraft are requested to throttle back immediately after takeoff to reduce noise and pollution, which could be indicated by projected on-screen boundaries. Another important factor would be the addition of control zones restricting airport controlled

6

airspace. This would be especially useful if the model was expanded on a macro scale to encompass encroaching control zones from multiple airports.

Having an airport set up, it should eventually be possible for a user to simulate aircraft landing and taxiing to the appropriate locations adjacent to a terminal building. Introducing a second aircraft while the first is already present will invoke further dependencies of minimum aircraft distances. Once in the correct docking position, aircraft support vehicles will need to make their way adjacent to the aircraft to provide ancillary services before the aircraft is ready to leave once again. Landing aircraft would be subject to minimum separation distances and taxi instructions issued by the control tower. Following these procedures, when contrasting a *Boeing 737-300* and an *Airbus A380*, the latter requires additional passenger and baggage handling staff and facilities, in addition to larger docking bays, having landed at an airport. Having successfully unloaded baggage, passengers and crew, these could be replaced by active components as part of the model, such as moving refuelling vehicles etc. Every aircraft that takes off has a different size and weight, thus affecting procedures that must be undertaken at an airport. The CAA also stipulates different procedures for taxi and takeoff depending on aircraft size, which could also be reflected in such an addition. Prior to departure, an aircraft will be required to queue behind all other aircraft also awaiting departure. The model will ensure that at all times, aircraft respect minimum required horizontal and vertical (post takeoff) distances from each other and on occasion, from airport support vehicles or buildings. Lastly, a useful addition in view of the aftermath following the 11 September 2001 events, focus of the model on a more granular scale to encompass security aspects would be a valuable addition to the model. A final improvement to the model would be to supplement it with LSD[8] functionality for superior multi-agent modelling, in order to discriminate and classify observables according to agent.

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[8]Language for Specification and Design