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Lean Improvements to Passenger Departure Flow in Abu Dhabi Airport: Focus on Data from the Check-in Element

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ABSTRACT

This is the second paper of three which concerns improving Passenger Departure Flow. The main aim of this paper is provide a summary of the research results, which includes both the reporting of empirical data collected at the Airport and the results obtained from simulation of existing flow for passanger departure process. The large quantity of data means this paper focuses on reporting data for the economy check-in element only. The project led towards development of rules for process of improvement for the entire departure process and explored the benefits of using the Lean philosophy for improving a range of airport processes. Airport processes are completely different than the manufacturing and other service sectors due to the complex interlinking between different stake holders such as airline regulations, national/international law etc.

Keywords* : *Lean philosophy, Passenger Departure Process, Airports, Abu Dhabi, UAE, Process Improvement, Passenger Flow, Variability

1 INTRODUCTION

TODAY, airports form a key part of global infrastructure in an increasingly globalized world. Abu Dhabi International Airport (ADIA) is a major international hub. Consequently, improvements in this airport are significant to both large and small airports worldwide and this project makes a major contribution to the various researches undertaken for several years into improving passenger departure flow including as [1], [2], [3], [4] because of its use of Lean Service techniques. The main advantage of using the Lean service technique is that despite of organisation's commercial interests, it allows improvement initiatives to be driven from the customer's perspective.

By 2013, ADIA had a handling capacity of around 12.5 million passengers annually. When the full expansion currently taking place is complete, the airport will have a capacity of 47 million passengers annually, many of whom are transit passengers. Terminal 3 is the home of Abu Dhabi's major carrier, Etihad Airways, one of the world's fastest-growing international airlines. Serving their needs effectively and efficiently while staying sensitive to the needs of passengers is a major strategic aim in this research programme.

The PhD-level research project described in this paper focused on applying the Lean methodology to the passenger departure process in Terminal 3.

There were three major objectives of the project: First, to develop a methodology to identify mixed levels of variability using predefined performance metrics identifying operational problems which influence Lean thinking about the efficient flow of passengers. Second, to identify individual operational cause-and-effect pathways and their ensuing root causes. Third, to use simulation modelling to develop a rule-based method to identify root causes and to propose Lean solutions to resolve them.

The first paper described the approach adopted to achieve the first two major objectives. This is the second of three papers which describes the empirical information collected during research and the results of simulation of existing flow and development of rules which allows the process of improvement to take place and explore the benefits of using the Lean philosophy for improving airport processes. Nevertheless, security constraints arising from the need to counter terrorism and organized crime mean that all empirical data cannot be published in this open paper though those with a genuine need to access this information may apply to De Montfort University's Research Committee for permission. Such permission will be granted subject to approval by National and Airport Security Authorities in the United Arab Emirates. Consequently and for space limitations in this paper, planning data and results are confined to just one element of the passenger departure process, 'Economy-Class Check-in'. This paper is organised in seven further sections. Section 2 briefly describes the departure process; Section 3 addresses data collection and generation, including that from simulation; Section 4 outlines important differences from previous Lean studies; Section 5 describes the preliminary analysis of simulation results; Section 6 provides a summary of the paper; and Section 7 the authors' acknowledgements.

2. THE DEPARTURE PROCESS

The departure process, shown simplified in Fig 1 is comprised of some 14 elements, numbered in Figure 1. Operations are divided into those which take place on the 'land side' (station groups 1-10) of the process and those which take place on the 'air side' which does not have access by the general public (station groups 11-14). For security reasons, this article restricts itself to the 'land side' and then only to operations involved in economy check-in of various types (stations 1-3). Each station group may consist of several processing stations. For the purposes of this research each processing station was then described in much greater detail with the appropriate number of individual processing stations incorporated into each station group. Various waiting and concessionary areas occur through the airport, sometimes divided by passenger class. These were assumed to be of infinite size.

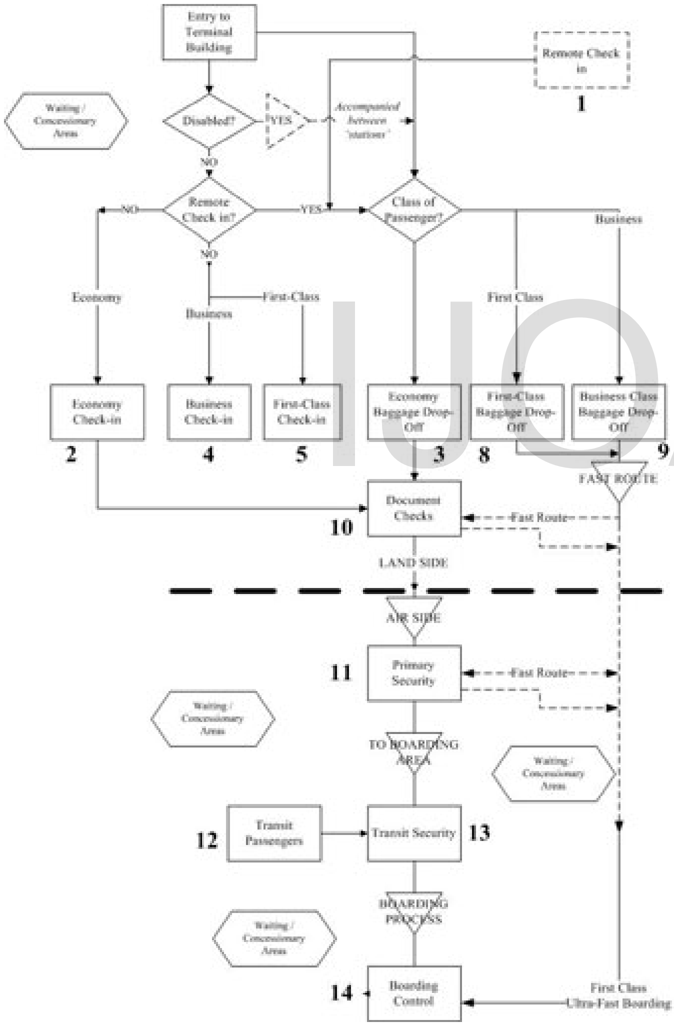

FIGURE 1
SCHEMATIC PASSENGER DEPARTURE PROCESS

3 DATA COLLECTION

3.1 Tools

During both stages of collecting qualitative data detailed certain important factors were noted.

1. Details of the Airport Service Quality (ASQ) performance benchmarking program, which mirrored almost exactly the collection of qualitative data proposed in this study.
2. The need for extreme caution in handling these data for security reasons.

In the first case, the Airports Council International (ACI), an international governing and quality assurance body for the airport industry developed a program first launched in 2007 called ASQ program [7], which provides a range of management tools to assist airports improve customer service and processes such as the passenger departure process. The total program involves seventeen key performance indicators throughout the airport measured through a series of observations carefully scheduled to ensure an accurate reflection of measurements of processing and passenger flow in airports. Since its launch the ASQ methodology has been tested in airports worldwide.

Part of the ASQ program is a suite of specially designed software operating on Personal Digital Assistant (PDA) devices. There seemed little point in 'reinventing the wheel' and so relevant parts of the ASQP program were used. The Airport Authority provided a software-enabled PDA to enable data collection. For secure handling of data, the ASQ program was linked directly to a secure computer storage facility heavily shielded from tampering. Adopting the ASQ method and PDA device meant both factors could be addressed at the same time.

3.2 Qualitative Data

As well as ensuring reliability and validity of data, a principal concern during research was to collect information about the local and international regulatory framework that governs all airport operations and all processing stations which could directly affect Lean improvement methods. The research also recognises new regulations may be imposed at any time, at short notice. Two methods achieved knowledge of these regulations:

1. A detailed literature survey which focused on regulatory matters;
2. Unstructured interview of managers for the different parties in Abu Dhabi Airport with responsibility for different processing functions within each of the groups of processing stations.

3.3 Quantitative Data

Data collection consisted of detailed observations of each process to collect random and specific data through sampling at each processing station [8], [9], [10]:

1. Process Times.
2. Numbers of Passengers.
3. Arrival Patterns of Passengers.

These provided sufficient quantity and quality of data to drive the program of Discrete Event Simulation using Simul8, as well as subsequent data examination and analysis.

The ASQ methodology lays down various measurement parameters in detail. ASQ requires multiple observations at each processing station during a 60 minute period in each processing station before moving to the next. During the 60 minutes a series of 10 minutes observations ('observation set') was taken and recorded on the PDA. If an observer arrived at the processing station and no queue was in place, ASQ required the observer to wait five minutes before the next observation

In each case, observations started when a passenger presented themselves to the processing station. Around twenty passengers were observed, whether singly or in groups and the 20th passenger from the queue identified. At the expiration of 10 minutes, or when the final or 20th passenger in the observation set was completely processed, recording of the observation set was terminated.

No measurements were made of passengers waiting in concessionary areas between processing stations or before the check-in queue. These holding areas were assumed to be infinite for practical purposes (Table 1). ASQ enabled the identification of variable factors most useful for measurement purposes and the most important key performance indicators in an airport setting [11].

3.4 SIMULATING THE DEPARTURE PROCESS

Simulation is defined as "the imitation of the operation of a real-world process or system over time" [12] and is used to ask 'what if' questions about the real process and helps to design improvements to it. An important objective for simulating the passenger departure process was to reduce Work-in-Progress (WIP) in the form of waiting or queuing passengers to free them to carry out discretionary activity and enjoy the airport's other facilities.

Computer simulation is built from a series of building blocks [13], especially in the case of (groups of) processing stations. This researcher used a twelve step Discrete Event Simulation model [12] described by Banks et al. Normally, in a manufacturing context one would consider processing time, queuing-time, reject and rework levels, and inventory holdings. In the departure process this translates into the time it takes for a processing station to deal with an individual passenger, the number of passengers and the time spent waiting in queues. 'Reject' would be when a passenger is stopped at any point during the departure process from proceeding to board the aircraft and continuing their journey. 'Rework' is where passengers are required to take part in another process. For example, when checking-in, baggage may be overweight and so a passenger is redirected to the excess baggage charging area before being allowed to re-join the check-in queue. In some cases, rework is mandatory by law. A certain percentage of passengers passing through security are required under international law to be subjected to additional security checks before being able to exit the security gate [14].

Previous researchers such as [3], [4], [15],[16] have used simulation to improve various elements of the passenger departure process shown in Fig.1. For the entire departure process, this involves many complex activities including data collection, model building, simulation, generating alternatives, analysing outputs, and presenting results [3]. This enables formulating and implementing recommendations based on these results. It is not normally possible to emulate, this using 'real-world' processes as they would create too much disruption within the airport. Simulation provides an alternative to investigate the real world processes under study other than airports; there are numerous other examples within the manufacturing and service sector, where simulation has been used to study the system under observation and to complement the process improvement initiatives. For instance, optimisation and standardisation of production process [17], investigation of system constraints [18], to validate the future state for a Lean transformation process by including the time based random variability for different processes, etc.[19], [20].

Here, Simul8™was used to mimic the dynamic nature of passenger departure process[21]. Simul8™ is a time-based visual model, which performs simulation after the researcher has drawn the process and input the necessary quantitative data. The simplified version of the flowchart is presented in this paper (Fig. 1) though in the actual model, each element of the departure process was more accurately produced in a total of eighteen detailed flowcharts.

The program accounts for all the resources and constraints involved and the way various elements interact with each other as time passes, calculating and displaying interactions between resources to provide an insight on how individual changes affect the whole process using Discrete Event Simulation. Table 1, shows details of each of the modelling elements in the passenger departure process, though in this case restricted to Economy-Class check-in for reasons given in Section 1 of this paper. Abu Dhabi Airport, like other major airports offers several alternative check-in processes. Only three of those choices offered within Terminal 3 of the airport complex are described here; Economy Self Check-in (1 in Fig. 1) Economy Standard Check-in (2 in Fig. 1); Economy Baggage Drop (3 in Fig. 1).

In Table 1, while there may be some division between different classes of passenger, the landside waiting and concessionary area may be used at anytime by passengers and to some extent the public prior to passengers going air side. Table 1 describes the various characteristics of different processing stations and concessionary areas divided into a name for the 'modelling element', what 'model type' it was in the simulation model, its numeric value representation in the same model and suitable descriptions which adequately explain its use.

The second horizontal division in Table 1 refers to queuing immediately before the relevant processing station, while the third division gives numerical values for economy check-in (only) which provided a snapshot relevant for the time the data were taken, though these vary periodically and seasonally and are to some extent left behind because of rapidly increasing demand in Terminal 3.

Simulation parameters are shown in Table 2 and Table 3 describes the input factors or variables used in the simulation.

Table 2 gives the variable name, also referred to as the 'Factor' in Taguchi methods [22], [23], [24] and its properties in the simulation model. Table 3 names the individual simulation values and describes or enumerated their respective value.

TABLE 1

Modelling Elements	Model Type	Attribute	Value (Variability Levels)			Description
Waiting Commerc'l Area Economy	Queue	Queue Size	Infinite			Quantity
Waiting Commerc'l Area First/ Business-Class						Number of passenger waiting based on their flight call
Waiting Economy Check-in Desk	Queue	Queue Size	Infinite			Quantity
Waiting Economy Self Check-in						Number of passenger waiting for check-in desk
Waiting Economy Drop-Baggage Desk						
Economy Check-in Desk	Process Station	Active Stations	8	5	3	All values vary for each experiment, which is derived from Taguchi array
		Cycle Time (Min^s)	2.76	1.93	1.56	
		Rework (%)	5%	3%	1%	
		Reject (%)	0.30%	0.20%	0.10%	
		Batch Size 8,3,1 (units)	10%,70%,20%	8%, 75%,17%	2%,88%, 10%	
		Baggage Status	90%,8%, 2%	90%,8%, 2%	90%,8%, 2%	
		% Operatives experience level	Low	Normal 80%	High	
			5%		15%	
		Daily Demand	4,944	4,091	3,515	
		Weekly Demand	34,606	28,639	24,605	
		Monthly Demand	150,370	124,445	106,913	

TABLE 2

Variables/Factor	Properties in Simulation
Batch size (passenger Group size)	Passenger number
	Distribution
Cycle time (Dwell time)	Time
	Distribution
Interval arrival time (Daily Traffic Fl	Passenger number
	Distribution
Queue Length Check-in (determines	Time
	Capacity
Staffing Capacities	Number of Resources
Aircraft size ,Load factors %	Passenger number
	Distribution
% Experience (level) of Operatives	Level skills
	Distribution
Baggage Problems (All Classes)	% Rework
	Distribution
Assigned Check-in Time	Time
	Distribution
Type of passengers	Passenger labels
	Distribution
Passenger Class	Passenger Labels
	Distribution
Has Bags?	Passenger Labels
	Distribution
Number of Processing Stations	fixed in facility and/or brought into operation
	Machine availability
Choice of Supplementary Facilities	Time
	Capacity
Layout of Processing/ Queuing Facil	Fixed facility and/or brought into operation
Time of Day	Passenger number
	Distribution
Security Statutory check	% Rework
	Distribution
Security High-Risk Warning	% Reject
	Distributions
Emigration (Fatal)	% Reject
	Distribution
Emigration /Visa Issues	% Rework
	Distribution
Check-in (all classes) (Fatal)	% Reject
	Distributions

TABLE 3

Simulation Parameters	Value
Results Collection Period	Represented the result of end of simulation time and all experiments were undertaken for Day.
Travel Time	Set to Zero, as the model represents a real passenger's flow process and evade the effect of any other factors that may change final results.
Random Time	No randomness as it represents a passenger demand at Abu Dhabi Airport, Terminal 3
Warm Up Time	Set to Zero.
Shift Pattern	0600-1400, 1400-2200, 2200-0600 equivalent to 24hrs per day.
Probability Distribution	Skewed distribution chosen because of the stochastic nature of the inter-arrival time.
Resources	All staff and equipment modelled according to task and shifts.

3.5 Measuring Variability

Design of Experiments (DoE) was first proposed in the 1920s by RA Fisher as a means of studying the effects of multiple variables simultaneously [24]. The next major advance in the technique came with the use of a methodology first developed by Genichi Taguchi working in Toyota [22] who began research on DoE techniques in the 1940s.

The Taguchi Method uses the methodology shown in Table 4. The entire three-step Taguchi procedure is 1) system design, 2) parameter design, and 3) tolerance design in optimising the departure process [22].

TABLE 4

(1) Planning the Experiment
Identify the main function side effects and failure mode;
Identify noise factors in testing conditions for evaluating the quality loss;
Identify the quality characteristics to be observed in the objective function to be optimised;
Identify the control factors and their alternate levels; and
Design the matrix experiment (orthogonal array - OA) and define the data analysis procedure
(2) Performing the Experiment
Conduct the matrix experiments using Taguchi's OA
(3) Analysing Experimental Results
Signal-to-noise ratio calculations
Analyse the data, determine the optimum levels for control factors and predict performance under these levels
(4) Confirm Results

When dealing with an existing architecturally fixed system such as those present in an airport one moves directly to step 2 – parameter design. The purpose of step 2 is to optimise the process's functional characteristics and thereby have minimal sensitivity to 'noise'. The Taguchi approach emphasises building robust quality into processes. This is achieved by carefully selecting parameters, which best define key elements of the process and reduce variability when those parameters are performed [25]. Taguchi refer to reduced variability as 'on-target performance' which associates a value to process quality by using the loss function. Taguchi proposes a holistic view of quality which relates quality to cost however one defines quality [26]. Thus one might define 'quality' in terms of passenger satisfaction, meeting the needs of the Airport Authority in terms of its economic model centred on payments from concessionary is or more specifically on the effective application of the Lean philosophy in reducing waste of resources. Parameter design involves selecting the important parameters of a process and to achieve this one must find the optimal settings of controllable factors so that the final process design is robust when confronted by various uncontrollable factors [23]. The underlying purpose is to increase awareness of the need to reduce variation and then to use a thorough systematic scheme of process optimisation which produces consistent performance and at the same time minimal variation, optimal cost and reduced cycle time [26].

Parameter design involves selecting the important parameters of a process and to achieve this one must find the optimal settings of controllable factors so that the final process design is robust when confronted by various uncontrollable factors [23]. The underlying purpose is to increase awareness of the need to reduce variation and then to use a thorough systematic scheme of process optimisation which produces consistent performance and at the same time minimal variation, optimal cost and reduced cycle time [26]. In this context, controllable factors are those which need to be optimised and over which the process designer has some control. Conversely, uncontrollable factors are those which are not under the designer's control. In the case of the passenger departure process, uncontrollable factors include those which are imposed by external authorities or by other factors such as weather or air traffic controllers, mechanical problems or any of those which will affect the passenger departure.

Parameter design uses orthogonal arrays which list controllable factors and specify combinations of settings of the factor level so that each factor appears an equal number of times at each level. Orthogonal arrays have special properties which serve to reduce the number of experiments necessary and are efficient when compared to many other statistical designs. One can calculate the minimum number of experiments based on the degrees of freedom approach using the following formula[27]:

$$N_{Taguchi=}1+\sum_{i=1}^{NV}(L_i-1) \tag{1}$$

While the partly experimental approach selected for research design is concerned purely with research and knowledge building, the Taguchi approach is based on practicality. From this perspective, using the Taguchi methodology goes a step further than the standard DoE methodology as it seeks to develop process designed which are insensitive to noise factors and that remain on target with minimum variability (Sarin 1997). Noise factors are those factors which either cannot be controlled or are too expensive to control (Unal and Dean 1990). In practice, many organizations use trial and error or study a single parameter at a time. This leads to lengthy, expensive and time-consuming improvement processes or in many cases premature termination of the improvement process because of mounting costs. The study of thirteen design parameters at three levels requires 313 (1,594,323) experiments to be carried out [26]. Normally this means a process design which has not been optimised because optimisation remains unfeasible. Taguchi's approach to parameter design provides a realistic answer.

Taguchi's approach is the systematic and efficient method of determining parameters of cost and performance whose objectives is to select the best combination of controllable parameters which lead to the most robust solution with respect to noise factors. The Taguchi Method needs only a small number of experiments and statistically, conclusions drawn from such small-scale experiments are valid for the entire experimental subject.

The next step is to determine the quality characteristic to be optimised, the main functions side effects and failure mode of the process under consideration. This enables identification of factors (parameters) whose variation have critical effect on process quality [26]

In this case, the Table 5 is one of ten which defines the factors used as a basis for designing the matrix experiment and for the design and analysis procedures based on controllable factors. The other nine tables are omitted from this paper for security purposes.

TABLE 5

Factor	Level 1	Level 2	Level 3
Active Stations	8	5	3
Cycle Time (min)	2.76	1.93	1.56
Rework (%)	5%	3%	1%
Reject (%)	0.30%	0.20%	0.10%
Batch Size 8,3,1 (Units)	10%,70%,20%	8%,75%,17%	2%,88%,10%
Baggage Status With Baggage, Hand Baggage, No Baggage	90%,8%, 2%	90%,8%,2%	90%,8%,2%
Percentage Of Operatives With Experience Level	High (3)	Medium (2)	Low (1)
	15%	80%	5%
Daily Demand	4,944	4,091	3,515
Weekly Demand	34,606	28,639	24,605
Monthly Demand	150,370	124,445	106,913

Next the standard orthogonal array was determined. This involved counting the total degrees of freedom (dof) found in the research study. This determined the minimum number of experiments needed to be run to study the effects of the factors involved. The researcher allowed one dof for the mean value and then one dof for each variables running at different levels.

Thus [23]

Total *dof*= (*dof* of overall mean + *dof* for number of variables running at different levels) (2)

Table 6 shows the rules for selecting standard orthogonal arrays when all experimental factors have only three levels [23].

TABLE 6

Number of Factors	Orthogonal Array to be Used
2-4	L_9
< 5	L_{27}

The next step was conducting matrix experiments using simulation closely modelled on the detailed flowcharts described earlier, then record the results.

4 IMPORTANT DIFFERENCES FROM PREVIOUS LEAN STUDIES

Several important differences are apparent when considering the empirical data, if one compares it to data which normally occurs in manufacturing processes and which makes the airport departure process is fundamentally different from normal Lean models. The ten most important differences are as follows:

1. Passengers are not inert components in a process but are rather thinking entities who may not always behave entirely as process designers conceive because they act in their own immediate interest or from unfamiliarity with the airport environment.
2. The individual elements of the passenger departure process at processing stations is not the responsibility of a single entity, but of several separately managed entities although the Airport Authority provides coordination.
3. The passenger departure process begins as a 'push' system and as the process later becomes a 'pull' system immediately before the departure gate.
4. Actual departure time, which provides the only 'pull' in the departure process is uncertain, normally due to factors outside the Airport Authority's control. Delays to actual departure may be large t at times.
5. Viewed over different periods (seasonally, monthly, weekly and daily) the departure process is the subject of peaks and troughs in demand which may be cumulative and which may occur several times during

each of these periods. Peaks and troughs are generally measured by airport authorities in terms of aircraft departures. This may be misleading when one considers the lead between different elements (i.e. processing stations) of the process. Thus for example, earliest call to check-in may be some four hours ahead of scheduled departure time creating different peak periods in each processing station.

6. Although the ‘passenger arrival process’ is not the subject of this research study, it was noted that peak aircraft arrival times differ from peak departures. Lags occur after touchdown for different elements of the process. The difference between peak arrivals and peak departures and their associated processes, which frequently use the same personnel may provide further improvements to human resource usage.
7. Passenger types may vary considerably from one type of flight to another depending on destination and peak flow of various types. For example, the person-by-person and group composition of seasonal passengers attending the Hajj in Mecca, will be different from long-distance flights to predominantly business destinations, which will in turn be different from flights which run to short and long haul holiday destinations. It was outside the scope of this study to consider these differences.
8. Individual processes may vary, sometimes at short notice or unpredictably because of external events, many of which may occur hundreds or thousands of miles away from the immediate airport environment as well as locally.
9. The strong regulatory and security environment which surrounds air travel overrides many consideration of process improvements. These also may change at short notice in reaction to external events anywhere in the world.
10. For economic reasons, the objective of airport authorities is not to reduce overall throughput time during the departure process, but to free passengers from attendance at individual processing stations to give them more time in concessionary areas. Some observers may see this as being directly contrary to Lean principles, though most airport authorities regard this necessary part of their economic model.

5. CONSTRUCTING THE SIMULATION MODEL

Some variables identified in the literature and described in the previous paper in this series [11]were unsuitable to incorporate in the simulation model. This was either because of local conditions in Abu Dhabi Airport; the specificity of variables to studies in which there were identified or because the nature of the model described was such that various factors should be combined in practice to avoid excessive and unnecessary complexity in the model.

The nature of each processing station is such that while some variables are common to all processes, each of the chosen variables must be considered in relation to specific processes. Thus a list of individual operations or tasks taking place within the process was prepared and used to construct the simulation model.

Such was the consequence of external factors, especially those related to terrorism and organized crime when appropriate and not directly related to flow within the simulation model, each processing station was treated as a ‘black-box’ with consideration only its inputs and outputs. Nevertheless, the approach taken in this case resulted in a significantly more detailed simulation model of the entire passenger departure process that those identified in previous studies.

A further problem concerned differences in terminology between the current application of Lean and the original Lean philosophy. Lean’s origin in manufacturing means that for clarity of understanding and incorporating into the simulation model, certain terms used in airport operations were matched with those used in manufacturing. Table 7 shows how manufacturing terms and airport operations were equated.

TABLE 7

Normal Manufacturing Term	Airport Departure Process	Airport Operation
Rework	Check-in (all classes)	Baggage problems such as overweight, unusual items, oversized items, problem contents etc.
Reject	Check-in (all classes)	‘Fatal’ problems with tickets, passports, visas etc which result in passengers not being allowed to fly or proceed past this stage.
Reject	Check-in	Passenger has outstanding debt problems or other issues which contravene Abu Dhabi/UAE national laws and prohibit flying unless resolved.
Rework	Emigration	Visa issues, problems with passports and other documents etc.
Rework	Emigration	Security issues; low and medium immigration risk warnings (national and international);
Reject	Emigration	‘Fatal’ errors with visas, passports and other documents such as producing fake passport and documents.
Rework	Security	Statutory checks on stipulated percentage of all passengers. Passengers with high-risk warnings when returned to the immigration queue after extensive checks are also taking to be rework.
Reject	Security	High-risk warnings which result in passenger not being allowed to fly or proceed past this stage.

6 ANALYSIS OF SIMULATION RESULTS

After the experiment was run, the researcher analysed results using signal-to-noise ratio (S/N) calculations on the orthogonal arrays which estimate the effects of factors on both variation and response mean [28].

Taguchi [29] made various recommendations on the several models of S/N ratios so that each could serve as a data summary which can combine to characteristics into which is the desired one [23], [30] such as 'on-target', 'above target' or 'below target'. In this case, the most appropriate model was 'on-target'. In this model (3), 'n' continuous observations are made and where y1, y2, y3 ….. yn represent the multiple values of performance characteristic 'Y' produced by experimental data. The 'on-target' value is 'τ'. The researcher maximised S/N as follows [23]:

$$\frac{S}{N} = 10\, log_{10}\left[\frac{\tau^2}{S^2}\right] \text{where}, S^2 = \sum_i \frac{(y_i-\tau)^2}{(n-1)} \qquad (3)$$

The calculation was performed by the Minitab™ program which produced graphical output of signal-to-noise ratio to facilitate better analysis. This program contains specific functions for orthogonal arrays which use control factors for the in the inner array and noise factors for the outer array. The control factors are those factors, which are potentially controllable to optimise the process whereas noise factors can affect the performance of the system which are not in control.

Thus the S/N ratio took both the mean and the variability into account. Experiments aimed to maximise the S/N ratio. This was equivalent to minimising the loss. This enables the use of S/N ratios to assure robustness of the process independent of target setting [23].However, such output cannot be interpreted in isolation. Instead one must interpret this output only with other methods such as of analysis of variance (ANOVA) and multi-factor analysis of variance (MANOVA)[31].

ANOVA is a statistical method used to compare variance of the response magnitude in percentage terms for each parameter in orthogonal experimental data. Mathematically, ANOVA is similar to linear regression analysis because both are parts of the 'general linear model'. They both achieve similar results.

While regression analysis is more flexible, ANOVA makes comparisons between groups and was specifically designed for analysis of experimental research. Regression analysis is more flexible because of the method's its ability to analyse various types of variables. Such flexibility is not needed when checking experimental models of this type. For this reason ANOVA has been commonly used in this context by various researchers such as [32], [33], [34]. Examples of Mintab's graphical output are shown in Figures 2 to 7 on following pages. These relate to the standard economy check-in process.

The statistical programme Stata™ was used to analyse variances using an extension of two-way ANOVA to understand the interaction effect between three or more independent variables (factors) and a continuous dependent variable. This method of analysis is normally referred to as "factorial ANOVA". Factorial ANOVA was chosen in preference to MANOVA because the use of Minitab to analyse signal-to-noise ratio negates the need for other statistical post-estimation techniques normally applied when either analysis method is selected. Whether ANOVA or MANOVA is chosen six assumptions underpin the use of these methods:

1. The dependent variable is measured at continuous level.
2. Each of the independent variables (factors) must consist of two or more categorical, variables from unrelated groups. In this case, Taguchi factors were generally presented as 1, 2, and 3 to satisfy this requirement in the Table of variables.
3. There is independence of observations for each of the factors.
4. There are no significant outliers in these data.
5. The dependent variable is approximately normally distributed for each combination of groups of factors.
6. There is homogeneity of variances for each combination of groups of independent variables. In this case, these assumptions were tested using Levene's test for homogeneity which is also available in Stata™.

A 10-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 2 to 7.

Dependent variables were:

1. 'Throughput'.
2. 'Average [Mean] Queuing-Time'.
3. 'Maximum Queue Size'.
4. 'Percentage of [processing station] Working [time]'.
5. 'Percentage of [processing station] Waiting [time]'.
6. 'Current Contents' [of pre-processing buffer] or WIP.

One should interpret graphical output as follows:

1. When the line is horizontal and parallel to the x-axis there is no main effect present and the response mean is the same across all factor levels; and
2. When the line is not horizontal, a main effect is present because the response mean is not the same across all factor levels. The greater the steepness of the line, the greater the magnitude of the main effect.

To better understand ANOVA results, the term 'highly statistically significant' is used when $P< 0.001$ followed by 'very statistically significant' $P < 0.01$ and then 'statistically significant' for $P <0.05$. To make interpretation clearer and avoid repetition, Dependent Variables and their abbreviations are bolded in the text and factor [or independent] variable enclosed in single quotes.

Fig.2shows the main effects plot for the mean values of throughput of Economy-Class Standard Check-in.

ANOVA results demonstrate the model itself is highly statistically significant, F(16,26) = 2.0715, p ≈ 0.000 as it was in all six cases tested where p varied between 0.0000 to 0.0004. In every case, interactions between the dependent variable and [the number of] 'Active Stations', F(2,26) = 3.369, p = 0 were highly statistically significant. Except for 'Maximum Queue Size' (Figure 5-4) where the interaction was very statistically significant F(2,26) = 3.369, p = 0.0056, interactions between dependent variables and 'cycle time' [of processing station] are highly statistically significant F(2,26) = 3.369, p ≈ 0 with p varying between 0.0000 to 0.0031.

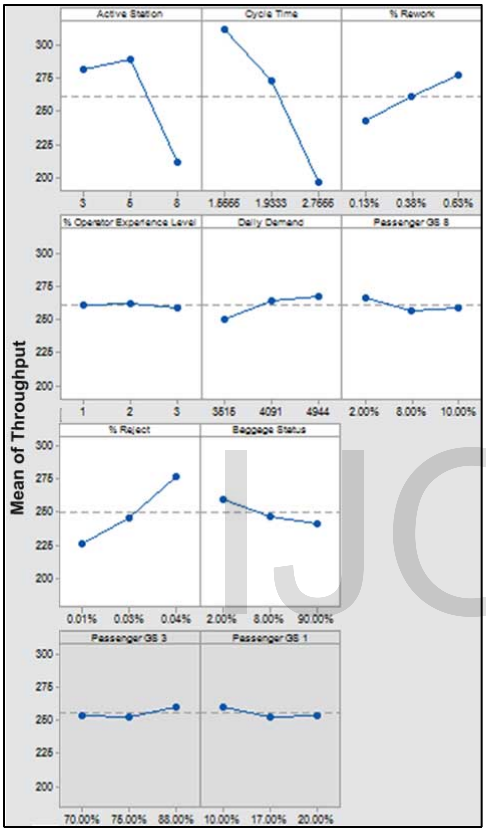

FIG. 1

ANOVA results demonstrate that for additional statistically significant interactions with dependent variable throughput (TP) (Fig. 2) are with '% [of] Rejects', F(2,26) = 3.369, p = 0.004 which is highly statistically significant, and % [of] Rework', F(2,26) = 3.369, p = 0.0339 which is statistically significant.

Fig.3 shows the main effects plot for the mean values of average queuing-time before Economy-Class Standard Check-in:

ANOVA results demonstrate that for additional interactions between Average Queuing-Time (AQT) (Figure 5-3), 'Daily Demand', F(2,26) = 3.369, p = 0.0091 and '% Rejects' F(2,26) = 3.369, p = 0.0091 were both very statistically significant. Interaction between AQT and '% Rework F(2,26) = 3.369, p = 0.0745 is statistically significant.

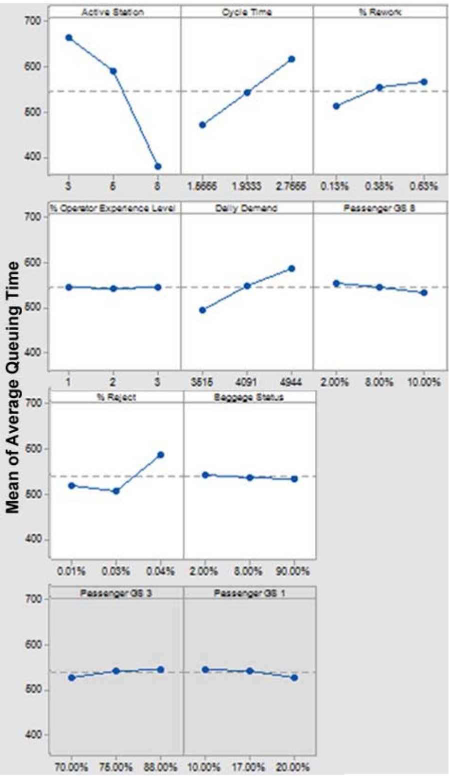

FIG. 2

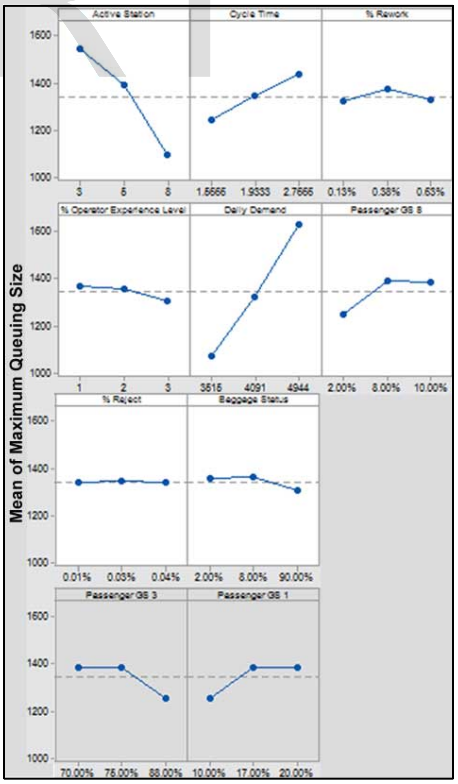

FIG. 3

Fig.4 shows the main effects plot for the means Maximum Queue Size and for Economy-Class Standard Check-in. ANOVA results demonstrate that for the additional interaction between Maximum Queue Size (MQS) and 'Daily Demand', F (2,26) = 3.369, p = 0 was highly statistically significant, while the interaction between MQS and [the number of larger group sizes] 'gs8', F(2,26) = 3.369, p = 0.0264 was statistically significant.

Figure 5 shows the main effects plot for means %age working of the processing station.

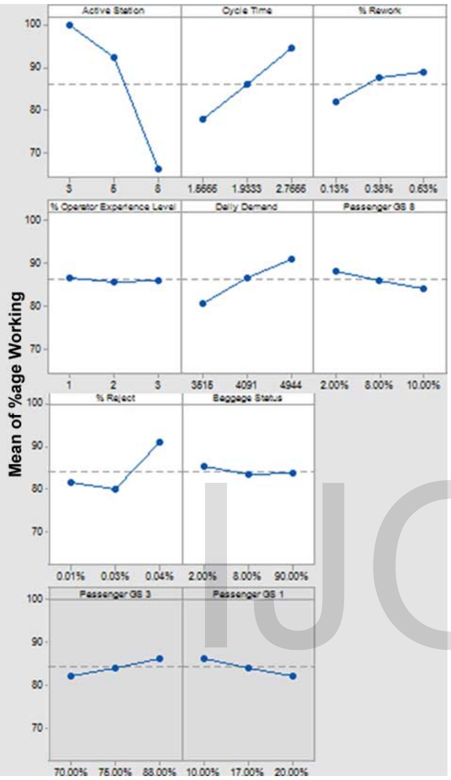

FIG. 4

In Fig. 5, ANOVA results demonstrate that for the additional interaction between % [of processing station] Working Time (%Wo) and % [of processing station] Waiting Time (%Wa) (Fig.6) was with '% Rejects', F(2,26) = 3.369, p = 0.0083 is very statistically significant, while the further interactions between %Wo&%Wa and 'Daily Demand', F(2,26) = 3.369, p = 0.0266 are both statistically significant.

Fig. 6 shows the main effects plot for the means of percentage working time of processing stations in use in Economy-Class Standard Check-in.

ANOVA results demonstrate that '% Rejects', F(2,26) = 3.369, p = 0.0083 which is very statistically significant, while the further interactions between %Wo&%Wa and 'Daily Demand', F(2,26) = 3.369, p = 0.0266 are both statistically significant.

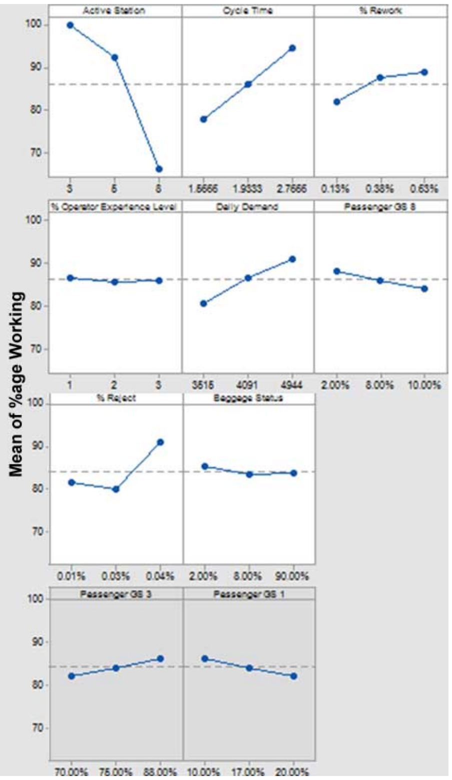

FIG. 5

Fig. 7 shows the main effects plot for the means of current contents (WIP) of processing stations in use in Economy-Class Standard Check-in. ANOVA results demonstrate that for the additional interaction between WIP with 'Daily Demand', F(2,26) = 3.369, p = 0.0062 is very statistically significant while the further interaction between WIP and '% Rejects', F(2,26) = 3.369, p = 0.0563, is statistically significant.

6.1 Simulation Model Results: Combined Processes

For the fifty-four statistical models tested for up to six dependent variables, and up to ten factor variables, a total of 137 highly statistically significant (HSS), 36 very statistically significant (VSS) and twenty-two statistically significant (SS) interactions are found though the models themselves accounted for a total of forty-nine at all levels of statistically significance. Of the remainder, most highly statistically significant interactions were for the number of 'Active Stations', followed those interactions between dependent variables and 'Cycle Time' of processing stations.

Such is the overriding influence of national and international regulations on the detailed operations of each processing station a positive decision was made not to measure their operations. This was further supported in that the additional time collecting and processing data would have serious violated SMART objectives [35]which recommend that projects should all recognise that all data collection should be specific to the achievement of the project, Measurable using available methods and resources, Achievable, Realistic within constraints of a strictly Time-framed project especially as much additional time would be needed to develop simulation models and analyse results.

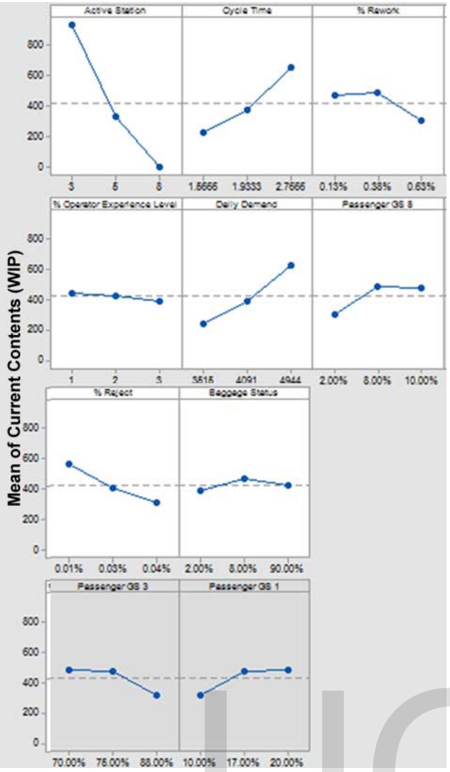

FIG. 6

While interactions between dependent variables and the factor 'Operator Experience' was found to be highly statistically significant in only five instances, observations and interviews with airport managers indicated that factor was capable of improving cycle time. Other factors such as percentages of 'rejects' and 'rework' were not sufficiently controllable as to relax standards in these areas could seriously infringe international rules and endanger passenger safety. In analysing of Taguchi factors and subsequent improvements to the simulation model, while to some extent imperfect, both adjustment of the number of Active Workstations and Operator Experience were selected as the two principal factors for improvement.

A primary purpose of all Lean systems if to minimise the consumption or provision of resources which add no value to the product or service or which are wasted [36]. In any Lean system resource utilisation processes should be designed to keep up with demand and in ideal systems visual controls provide an immediate signal when of the operation condition of the process and when to apply change [37]. Ideally, controls should be self-regulating and worker managed and these frequently involve Kanban-type systems.

7 CONCLUSIONS AND FUTURE WORK

Acting on the first stage analysis of these data presented in this paper above a series of improvement rules were developed to take account of the two most important findings. The need to provide processing capacity where and when it is required in the form of active processing stations, and the need to reduce cycle time. Each must be achievable in a simple, visually controllable way. The result was a series of rules capable of progressively increasing operating capacity using all underutilised resources, and rules which this research describes as 'If Rules' capable of giving the necessary visual signals to the workforce. These rules, together with the conclusions on this research project will be described in the next and final paper in this series.

In summary, the special environment of any airport, especially a major international hub made applying Lean principles difficult. This resulted from the large presence of Class I wastes or muda which could potentially change, perhaps dramatically, at short notice. This made this research significantly different from previous applications of Lean philosophy. Also, large, cumulative variations in demand set in an environment where rapid expansion of the airport is taking place also created major difficulties because of the shifting flow of passengers. Despite this, the research succeeded in achieving its aim and developed various rules from parameters based on the acronym SERVICE and an associated implementation methodology based on the Lean philosophy. Together these will help airline managers and staff to eliminate the waste of available resources and so increase passenger flow through various stages of the process in line with Lean philosophy.

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