

# **AN OPTIMISATION STRATEGY FOR SMALL AIRPORTS**

by

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## Declaration

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## **Abstract**

The aviation industry is an extremely dynamic industry where all stakeholders need to ensure that the operational margins are clearly identified and adhered to. Failure to actively and continuously streamline operations might cause almost immediate negative effects to a firm. Or in the worst case, might even cause overnight insolvency and closure.

Just as for the other stakeholders it is equally important to the Airport Operating Authority to be able to offer to its clients all required operational systems. In order to be able to make an operational profit, it is important that the Airport Operating Authority does not waste scarce resources on maintaining oversized components within these systems.

The components of these systems are all intertwined and most play an important role in the smooth running of the operations of the airport as a whole. It is clear that, if one of these components is optimised, it should optimise the system it forms part of which again should be beneficial to the airport-operational system as a whole.

In an effort to be able to identify those components that will have the biggest overall effect on airport operations, it is proposed that the method of Analytic Hierarchy Process be used. This method allows one to compare components that, under normal circumstances, is considered to be incomparable. In other words, the AHP allows you to compare apples with oranges.

Once these components are identified, one can use quantitative methods like regression analysis to identify a more optimum solution.

This strategy does not promise a golden answer to operational problems but will assist an airport authority eager to have as lean as possible operations.

It can be concluded that the strategy of identification, through utilisation of the Analytic Hierarchy Process, and optimisation, through Quantative Methods, affords the analyst a systematic approach to increase financial viability and sustainability of an airport which may otherwise place a tremendous load on limited resources.

## Opsomming

Die lugvaart industrie is 'n ongelooflike dinamiese industrie waar alle rolspelers 'n baie fyn oorsig moet hê, en behou, rakende hul bedryfs marge. Die gebrek aan gedurige verfyning van bedryfs-hulpbronne kan 'n onmiddellike nadelige effek op die rolspeler se bedryfs-marge hê. Dit het in die verlede al gelei tot die skielike bankrotenskap en ondergang van gevestigde firma.

Net soos die ander rolspelers in die industrie, is dit vir die Lughawe Owerheid ook belangrik om die benodigde sisteme daar te stel sodat verwagte dienste gelewer kan word. Maar op dieselfde toon is dit nodig dat die Lughawe Owerheid nie skaars hulpbronne spandeer op die onderhouding van oorbodige of onnodige groot komponente van die onderskeie sisteme nie.

Die onderskeie komponente van die verskeie sisteme is meestal op een of ander manier onderling afhanklik en ondersteunend van mekaar. Dit is egter duidelik dat, sou een van die komponente geoptimeer word, dit 'n positiewe uitwerking op die betrokke sisteem in geheel sou hê asook op die globale lughawe bedryfs-sisteem.

Dit is dus belangrik om daardie komponente wat die grootste impak op die onderskeie sisteme sal hê, te identifiseer. Om dit te doen word dit voorgestel dat van die Analitiese Hierargiese Proses (AHP) gebruik te maak. Hierdie proses laat toe dat komponente wat nie dieselfde eienskappe het nie wel vergelyk kan word sodat 'n onderskeid en hierargie geskep kan word. Sodra die komponente geïdentifiseer is wat die grootste uitwerking op die verskillende sisteme sal hê, kan 'n meer optimale oplossing gesoek word deur die gebruik van kwantitatiewe metodes soos byvoorbeeld Regressie Analiese.

Dit is dus duidelik dat die strategie van identifisering, deur gebruik van die "AHP", en optimisering, deur kwantitatiewe metodes, die analis 'n werktuig gee om op 'n gestruktureerde manier die lewensvatbaarheid van 'n lughawe te verhoog wat andersins groot druk plaas op skaars hulpbronne.

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## List of Symbols

$\lambda_{\max}$	-	Maximum Eigenvalue
n	-	Number of
P	-	Priority calculated from the AHP
W	-	Weight derived from pairwise comparison
f(...)	-	function of...
y	-	Dependent Variable
x	-	Independent Variable
$\hat{y}$	-	Predicted y value
$\bar{y}$	-	Average of y
$\bar{x}$	-	Average of x
$R^2$	-	Correlation Index

## List of Abbreviations

IATA	-	International Air Transport Association
ICAO	-	International Civil Aviation Organization
MTOW	-	Maximum take-off Weight
ATC	-	Air Traffic Control
ARFF	-	Airport Rescue and Fire Fighting
DCA	-	Directorate of Civil Aviation
NAC	-	Namibia Airports Company
AHP	-	Analytic Hierarchy Process
CR	-	Consistency Ratio (Overall Inconsistency)
CI	-	Consistency Index
MRCI	-	Mean Random Consistency Index

- LP - Linear Programming
- GA - General Aviation

## **List of Addendums**

Addendum 1: Typical Feedback for Pairwise Comparisons

# Chapter 1 - Introduction

The purpose and rationale behind the original construction of airports throughout the world keep on changing as different external and internal dynamics continue to influence the existence of an airport. Typical dynamics influencing an airport can be found in the natural, social, economical, and technological environment of an airport.

The African continent has a very recent history of conflict when the people of the continent strived to secure their place in the international arena. These conflicts were, and sometimes still are, associated with external, international super-powers outside of the continent that commit vast resources to a conflicting party with the secondary objective of being in a position to make a more favourable bid on the vast economical resources of Africa.

Part of this commitment was/is the development of airport infrastructure in conflict zones. It was evident, since the Second World War, that the party with aerial dominance has a far greater prospect of succeeding in conflict than its counterpart. This is not only associated with tactical, combat related use of the airfields, but even more so for logistical support of the battle-front.

*Once the command of the air is obtained by one of the contending armies, the war must become a conflict between a seeing host and one that is blind.*

— H. G. Wells

Typically these airports are then used as civilian airports once the conflicts end, leaving the responsible authority with a host of problems as the purpose of the airport and its associated operations, change.

The scenario described above is only one example of the change of the reason for being of an airport. It is obvious that it's impossible to derive at a generic recipe to change an airport and make it viable again but this thesis will look at factors that need to be investigated before any change can be implemented. It is only once all these factors are known and measured, that any change can be planned and implemented.

This thesis will therefore research a method to explore the viability of an airport as a system in its entirety and the required optimisation of the associated system components with specific emphasis on infrastructural components.

A viable airport needs to be an asset to its host country rather than an inherited white elephant kept alive for no apparent reason other than that it would not be deemed appropriate to let it fall into disrepair.

## Chapter 2 – Objectives and Scope of the Study

*Airports must plan for their future using a sustainable development strategy. Airports should not be expanded to meet year-on-year growth forecasts. Before airports embark on increasing the size and ultimate complexity of their operation they should be looking to rationalise processes and common tasks. Efficiencies in the undertaking of airport processes tasks should be refined and streamlined on an ongoing basis before the last option (to build more infrastructure) is chosen.<sup>1</sup>*

### 2.1 Objective

As a result of the greater emphasis placed on the economical well-being of governments, all state departments and state owned enterprises find themselves more and more in the position of striving to find the most economical operational solution to their field of business.

In developing countries, added pressure is put on governments and governmental institutions to pursue corporate governance. Donor countries require *inter alia* proof of consistent transparency and proper financial management of financial resources before additional resources are released to a developing country.

In light of this, it only stands to reason that any institution responsible for the development, operation and maintenance of infrastructure with a high capital value, like airports, need to look at the optimised utilisation of its resources in general and its financial resources in particular.

The adoption of a strategy to increase the viability of an airport as a system through the optimisation of the different components is therefore of utmost strategic importance for the management of any given airport.

This thesis will take the reader through the process required to optimise the different components of the airport and in particular to identify the crucial components necessary to ensure that effort is afforded to those areas that will achieve the optimal results.

### 2.2 Assumptions

It is important to first set out and explain the assumptions that support the document. This will assist the reader in clearly understanding and appreciating the scope of the document.

### **Assumption 1 (Size of the Airport)**

Airport "size" is usually judged by the number of aircraft movements (takeoffs and landings) made each day. The physical extent of the infrastructure does not have any influence on deciding whether an airport is small or not.

The typical airport under consideration in the optimisation strategy contained in this document should, per above definition, be considered as a *small* airport. This is important for three reasons.

*Firstly*, the airport authorities at small airports are normally under more financial pressure than their larger counterparts as their aeronautically associated income tend to be limited. These authorities therefore have a larger need for optimisation.

*Secondly*, the physical infrastructural components tend to be more limited in quantity, while associated operational systems are less complex than that for larger airports. This makes the identification and optimisation processes far less complicated than can be expected for large airports where more complex inter-relationships exist between the different operational systems.

*Thirdly*, the number of stakeholders at a small airport is minimal and may even be limited to only the airport authority. This makes the actual implementation of the findings of the study more likely since the presence of more stakeholders at an airport inadvertently lead to more involved decision making processes, sometimes politically-based, with objections to change.

The only yard-stick for defining airport size currently in the industry is by IATA which defines small airports as all airports with the capability to process flights and passengers through its runway and terminal infrastructure where the amount of passengers are less than 1 million people per annum.<sup>2</sup>

Airport authorities will have to decide for themselves if and how the strategy developed in this document (thesis) can be implemented at their airport/s.

### **Assumption 2 (Origin and Ownership)**

The typical small airport referred to in this study started out as military airports which were subsequently transferred to a civil authority to facilitate civil aviation operations. This results in two important concepts:

- That the current authority was not responsible for the original development of the infrastructure. This concept implies that the airport authority is sometimes presented with an enormous amount of infrastructure both in value and quantity.

- Resultant from the above it inevitably also means that some of this infrastructure is either not required for civil aviation operations or the capacity of the infrastructure supersedes the actual requirements for normal operations at the airport.

## 2.3 Scope of the Study

Following the assumptions indicated above, the limitations of the airport considered for this study can be identified as:

### 1. Low Traffic

As indicated previously in the document, the classification of an airport to be “small” relates to the fact that the traffic count is low. The airport relevant to this study by definition falls within this “small” category.

### 2. Limited Funding

The motivation behind the strategy to be developed here is that the airports under consideration usually experience a lack of re-investable income, which can mainly be attributed to limited air traffic-related revenue. This is due to a double-negative effect experienced by this small airport where not only the volume of traffic is limited, but the bulk of aircraft using the airport also tend to be in the “less than 5700 kg” category. Since the landing fees are calculated based on the maximum take-off weight (MTOW) of aircraft, the predominant incidence of light aircraft at the airport subsequently results in below average aeronautical revenue.

### 3. Superfluous Capacity of Components

One of the assumptions supporting the strategy is the reasonable possibility that the airport under consideration has superfluous capacity in relation to some of its operational systems. This is normally the case if an airport was “inherited” or changed in function. The likelihood of superfluous capacity in an airport originally developed under its current authority is very limited.

### 4. No time constraints

One of the characteristics of small airports is the lack of time-related constraints, such as slot allocations, to operations. The low traffic incidence

normally result in the phenomenon that landing times, manoeuvring times and turnaround times are not as big an issue as at larger airports to the point of not being an issue at all. Optimisation in relation to time, e.g. speedier turnaround time requirements, therefore has no real value at the typical airport under consideration.



## **Chapter 3 – System & Component Identification**

The first step of optimisation of the components of a system involves the identification of the different components. This is done by the systematic breakdown of the different systems to their individual components. If these individual components are then optimised, it will positively influence the sub-systems and consequently the global system.

The main operational systems of an airport are:

1. Passenger Facilitation
2. Aircraft Manoeuvre and Service System
3. Safety & Security
4. Cargo Facilitation

A breakdown of the different systems into sub-systems and ultimately into the various components follows.

### **3.1 Passenger Facilitation**

This system involves all direct and other related components that are required for the safe facilitation of both arriving and departing passengers. This starts from the time that a passenger checks in for their flight until they board the aircraft and again from the time that a passenger disembarks from an aircraft till the time that they leave the terminal building.

The typical sub-systems are:

#### **3.1.1 Passenger Facilitation**

The first sub-system involves the management of the movement of the passengers themselves. This governs all the processes that a passenger needs to go through before embarkation or after arrival. The main components for this sub-system are:

- Ticketing Facilities
- Check-in Counters

- Airside Waiting Seating Facilities
- Airside Restrooms
- Duty-free facilities
- Boarding Gate/s

### 3.1.2 Ground Handling

The second sub-system analysed is the ground-handling aspect. On small airports, this normally involves the operations associated with the transfer of baggage to and from the aircraft. Other ground-handling operations like cleaning are normally done at the aircraft operator's base station to save costs. These cleaning duties are usually performed by either the pilot (for chartered aircraft) or ground-handling staff (for scheduled aircraft)

The most important components are:

- Baggage Movement System
- Ground handling personnel
- Refuelling
- Cleaning Personnel

### 3.1.3 Meeters- & Greeters Management

Passengers are frequently accompanied by persons who will not travel along but are merely present in a supporting capacity. This includes *inter alia* family members or friends that come to see a passenger off or fetch the person just arriving from a flight. It also includes people involved with the transport of passengers to and from the airport for instance bus-operators, taxi-service providers or car rental agents.

- Seating
- Restrooms
- Car Rental Facilities
- Taxi, shuttle or bus services
- Refreshment Facilities

- Restaurant/Coffee shop
- Public Shops

#### 3.1.4 Landside Vehicle Management

The management of vehicles on the landside goes hand-in-hand with the abovementioned management of people accompanying the passengers. The correct management of vehicles is required to reduce the associated safety-risk carried by the airport operator.

- Access Roads
- Parking Areas
- Drop-off Zones
- Short Term Parking
- Long Term Parking

### 3.2 Aircraft Manoeuvring System

This system accommodates all components required to facilitate an arriving aircraft, accommodate and service it safely and finally assist it in safe departure. A proper aircraft surface movement guidance and control-system is required at all airports to ensure the safe movement of aircraft on and around the airport. Apart from the fact that aircraft *per se* are extremely expensive, accidents may have catastrophic consequences and thus aircraft-related safety systems always have a high priority at an airport.

The typical sub-systems are:

#### 3.2.1 Runway, taxiways and apron areas

These are the main facilities of an airport and are the area constructed to be used by aircraft for take-off, landing, parking, loading and off-loading.

- Runway,
- Taxiways
- Apron (Including Ramp) also known as “Movement Area”

### 3.2.2 Air-traffic control (ATC)

Air-traffic control stands in the centre of the safe management of aircraft both in the air and on the ground. Air-traffic control is usually limited to the sky around the airport as well as all activities in the manoeuvring area i.e. the runway/s and taxiways.

Though pilots are trained to safely navigate without the assistance of a third party, this is limited to areas with low traffic and should never be seen as an acceptable alternative to Air Traffic Control.

The main components are:

- ATC tower
- ATC Equipment
- Movement Guidance Systems
- ATC-personnel

### 3.2.3 Aircraft Marshalling and Apron Control

This function is usually separated from the Air Traffic Control and control is limited to the movement area only i.e. the apron and ramp. This function ensures the safe movement and parking of aircraft while moving to and from the taxiways. View from the cockpit is limited to the sides and stern of the aircraft making manoeuvring a dangerous task.

### 3.2.4 Hangars and Hardstand Areas

Airports that are being used as a base-station by an aircraft-operator, normally has hangars for long-term storage of aircraft. This is mainly to protect the aircraft against the elements but also to limit potential vandalism.

Hard-stand areas are concrete portions that are normally used for short-term parking of aircraft. The reason for the hardstand areas is to prevent damage to the apron since the latter is normally constructed from earth or bitumen and the combination of weight, heat and fuel-spillage has a negative impact on the apron-area. Hardstand areas at airports prone to high-velocity winds may also be equipped with tie-downs to prevent damage to aircraft.

- Aircraft Overnight Parking Areas
- Hangars (For Long Term Parking of Aircraft)

### 3.3 Safety & Security

Security in airport operations has in the recent past increased in importance. After the September 11, 2001-incidents that took place in the United States of America, the safety and security of airports became an even higher priority and requirement in the international aviation industry.

The main objective of security operations are the safe-guarding of aircraft and passengers both on the ground and en-route. This is *inter alia* done by making a clear distinction between airside and landside areas.<sup>3</sup>

“Airside” is the areas used for the convergence of the passengers with the aircraft, the movement- and manoeuvring areas of the aircraft and all areas set aside to house service-providers that directly interact with aircraft and/or passengers. This area is to be “sterile” at all times meaning that no vehicle or person will be allowed to enter this area if it did not undergo strict security screening.

“Landside”-areas are all those areas that form part of the airport’s operational areas but excluding the airside areas. Landside areas are generally open to the general public.

The sub-systems related to safety and security are:

#### 3.3.1 Security Screening

Screening of people is done before they enter the airside. This is done by having any luggage pass through X-ray scanning equipment where trained security personnel scan the x-ray images for suspected contraband or dangerous material.

Persons are required to pass through a walk-through metal detector which picks up traces of metal thereby reducing the risk of dangerous material being taken on board an aircraft.

The main, most commonly used, components are:

- X-Ray Screening Equipment for Passengers and Luggage
- Walk-through Metal Detection
- Handheld Metal Detector Wands
- Policing and Security Personnel

### 3.3.2 Immigration Control, Customs & Excise

All airports which are designated points of entry and exit into a country need to have at least these two functions available to persons entering and leaving the country.

Immigration control oversees the cross-border migration-processes of people.

Customs & Excise controls the movement of imported and exported goods and merchandise over international borders and collects relevant taxes and duties.

- Office Facilities
- Front Desk Facilities
- Personnel

### 3.3.3 Airport Rescue & Fire-fighting (ARFF)

Rescue and Fire-fighting is one of the core responsibilities of an airport authority. Approximately 5% of aircraft accidents take place en-route whilst 15% take place within the airport approach areas i.e. within 15 miles of the airport. The other 80% takes place on the active runway, overrun areas or clear-zones. A plot of accident locations show that almost all of these accidents take place within 500 feet (152 metres) of the active runway centreline and 3000 feet (914 metres) off the runway thresholds.<sup>4</sup>

The airport premises are therefore, strategically, the optimal place to accommodate Rescue and Fire-fighting services.

ICAO guidelines stipulate that any accident site on the airport-premises need to be reached within a maximum period of three minutes thereby increasing the rate of survival after an accident.

The minimum, and main, components are:

- ARFF Vehicles
- ARFF Equipment
- ARFF Personnel
- Fire Station

### **3.4 Cargo Facilitation**

Cargo Facilitation as a system will not be considered in this thesis as the cargo-component for normal airports, except those airports registered as cargo-handling hubs, tend to place a relatively small load on the airport infrastructure. At most small airports, no cargo handling is done except for a small amount of belly-cargo brought in by passenger-carrying aircraft. This cargo is normally handled as part of the baggage handling system of the airport with minimal deviations.

Except where a small airport is operated as a cargo hub, the cargo-system can be deemed as having no substantial influence on the infrastructural capacity requirements.

### **3.5 Preliminary selection**

From the four sections above the following deductions can be made:

- Even for the smallest of airports, there are a host of sub-systems and components that have an influence on the functionality and feasibility of that airport.
- It will be impossible to rank the main systems in order of importance as all these systems are inter-dependent.
- It will be an enormous task to attempt to rank all components, both operational and infrastructural, in order of importance mainly due to the number of components. Operational- and infrastructural-requirements may change from time to time which will also impact on the ranking of components. This will make the model both difficult and cumbersome to use and update.
- It may be that some of the components or sub-systems may not be eligible for change as they are statutory requirements or may not be under the jurisdiction of the specific management. It does not mean that the airport authority must turn a blind eye to the systems and infrastructure associated with other stakeholders. It is just easier to address one's own systems first than persuade another to change theirs.

The air-traffic control sub-system in Namibia for instance, is under the jurisdiction of the Directorate of Civil Aviation (DCA) whilst the management of the airports are under the jurisdiction of the Namibia Airports Company (NAC). This means that the NAC can influence the optimisation of any components related to air traffic control to a limited extent.

It is therefore evident that the Airport Management will be required to do a preliminary selection of those sub-systems that not only can be optimised but also where optimisation will have sensible/valuable impact.

It may be that, for instance, the optimisation of a runway has a significant influence whilst the optimisation of the amount of dustbins in a terminal building may have negligible value.



## Chapter 4 – The Analytic Hierarchy Process as a Decision Making Tool

The Analytic Hierarchy Process (AHP) is a Multi Criteria decision making method that was originally developed by Professor Thomas L. Saaty. It is, in short, a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price or weight, or from subjective opinion such as a feeling of satisfaction or preference.

The AHP therefore can accommodate, to a certain degree, some inconsistency in judgement associated with subjectivity. The ratio scales are derived from principal Eigen-vectors and a consistency ratio is derived from the principal Eigen-value. The ratio scales give an indication of the relative priorities of the alternatives amongst one another.

### 4.1 Explanation of the Analytic Hierarchy Process

The AHP-process can be summarised as follows:<sup>5</sup>

Step 1: Model the problem by clearly identifying the following three aspects or hierarchy:

- The Goal, focus or objective of the study.
- The Criteria used to reach the goal.
- The alternative solutions.

Step 2: Establish the priorities of the different criteria by pairwise comparisons between each other. This will enable the analyst to derive a priority vector for the criteria themselves which will be used as basis for further calculations.

Step 3: Establish the priorities of the different alternatives for each criterion separately by using pairwise comparisons. This is done by the calculation of the geometric mean of each row of the matrix. It then leaves one with a priority vector specific to each criterion.

Step 4: Synthesize the judgement priorities calculated under Step 2 to derive at a hierarchical set of overall priorities of the alternatives *relative* to each other.

Step 5: Check the consistency of the results.

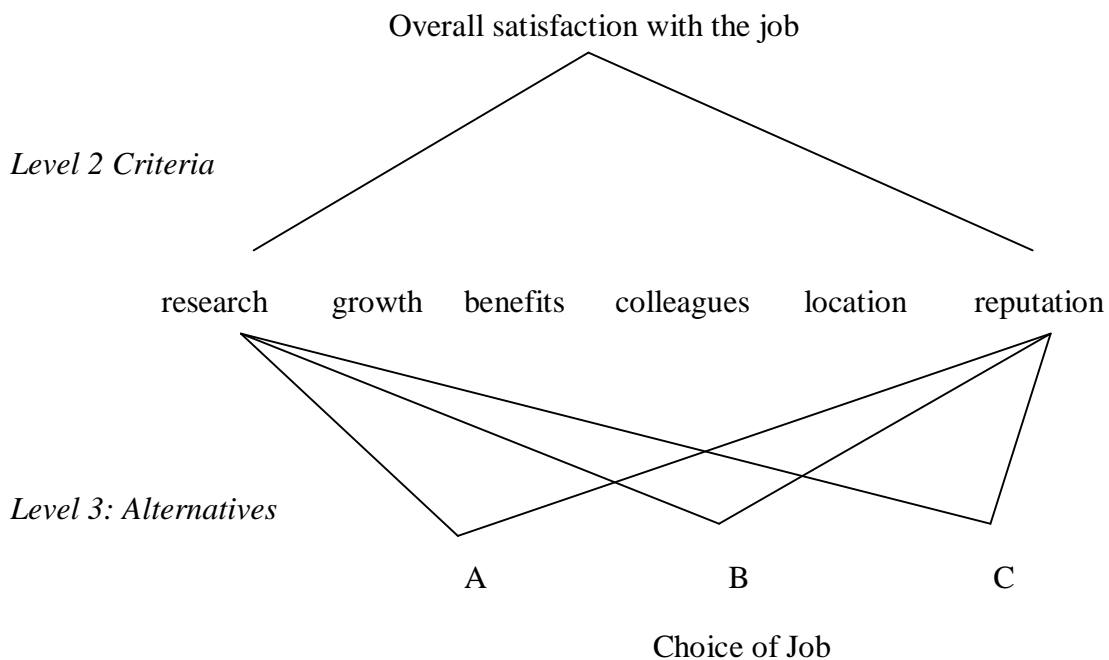
Professor Saaty used the following example to illustrate the AHP-principle of decision-making.

Level 1 refers to the objective of the exercise. In this case, the person wants to identify the job that best satisfy all the criteria he identified as being important at a workplace.

Level 2 refers to the Criteria or Attributes he decided will have a significant influence on his overall satisfaction at the workplace.

Level 3 indicates the three possible alternative job-offers.

*Level 1: Focus/Objective*



The process then dictates that for each criterion, any two alternatives are compared against each other and a value indicating the relative weight against each other is assigned.

It is important to note that, if the calculations are done by hand, then the corresponding weight for the pairwise comparison is assigned to alternative with the *lowest* weight i.e. a “penalty” is assigned to the alternative with the lowest impact.

Software such as *Expert Choice*® however requires the user to assign the weight to the stronger value in an effort to make the software more user-friendly. The transformation of the values is done as part of the operating algorithm.

This means that the importance of the criteria could be approximated by the AHP by the use of pair-wise comparisons.

This is done by answering two questions for each pairwise comparison:

- Which of the two alternatives is the more important one in respect of the criterion under consideration?
- How strong is this importance (On a scale of 1 – 9)

The Scale of Relative Importance (according to Saaty) used for assigning relative weight between two alternatives for a specific attribute looks as follow:

**Table 1: Table of Scale of Relative Importance**

<b>Intensity of Importance</b>	<b>Definition</b>	<b>Explanation</b>
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and Judgement slightly favour one activity over the other
5	Essential or Strong Importance	Experience and Judgement strongly favour one activity over the other
7	Demonstrated Importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute Importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
$\frac{1}{n}$ Reciprocal of numbers	If an activity has one of the abovementioned number compared to the second activity, then the second has the reciprocal value when compared to the first <sup>6</sup>	

As can be seen from the above, the scale does allow one to make use of experience and judgment to determine the extent of comparison between any two components.

All these values are presented in a series of matrices showing the results of all the comparisons done. These matrices are then used to compute the score of each alternative in relation to the rest i.e. relative prioritisation of the alternatives. This has the added advantage that a hierarchy of significance or influence of all the alternatives is developed.

## 4.2 Determination of the Criteria-specific Priorities and Consistency

The “consistency index” gives one an indication of the consistency of the pairwise comparisons done between the different alternatives. The rule of thumb is that, if the Consistency Ratio (CR) is less than 10%, the judgement matrix is considered to be adequately consistent. If the CR value exceeds the value of 0.1 it is recommended that the pairwise comparisons are re-evaluated.<sup>7</sup> A too-high consistency ratio means that the inconsistency between judgements/criterion is so high that it may appear to be random thereby reducing relevance to the options.<sup>8</sup>

The Consistency Ratio is calculated as follows (and illustrated with an example):

The decision-maker derived at the following judgement matrix after pairwise comparisons were done for a specific criterion:

<b>Criterion</b>	<b>A</b>	<b>B</b>	<b>C</b>
<b>1</b>			
<b>A</b>	1	6	8
<b>B</b>	1/6	1	4
<b>C</b>	1/8	1/4	1

1. The maximum left eigenvector is approximated by the geometric mean of each row.

This is calculated by drawing the  $n^{\text{th}}$  root of the multiplication of the values of each row where  $n$  equals the number of elements in each row. The weight obtained for each row is then normalised against the summation of all the weights.

For the abovementioned matrix, the calculation is then:

$$\text{For Row A: } \sqrt[3]{(1 \times 6 \times 8)} = 3.634$$

$$\text{For Row B: } \sqrt[3]{\left(\frac{1}{6} \times 1 \times 4\right)} = 0.874$$

$$\text{For Row C: } \sqrt[3]{\left(\frac{1}{8} \times \frac{1}{4} \times 1\right)} = 0.315$$

$$\sum_{\text{Row A}}^{\text{Row C}} = 4.832$$

$$\text{Normalised Weight for Row A} = \frac{3.634}{4.832} = 0.754$$

The priority vector for the matrix above is therefore (0.754, 0.181, 0.065)

2. Secondly the approximate maximum eigenvalue ( $\lambda_{\max}$ ) is obtained by adding the columns of the decision matrix and multiplying the resultant vector with the priority vector.

$$\begin{aligned} \lambda_{\max} &= \left[\left(1 + \frac{1}{6} + \frac{1}{8}\right) \times 0.754\right] + \left[\left(6 + 1 + \frac{1}{4}\right) \times 0.181\right] + \left[\left(8 + 4 + 1\right) \times 0.065\right] \\ &= 3.131 \end{aligned}$$

3. Next the calculation of the Consistency Index (CI) is done by using the formula:

$$(\lambda_{\max} - n)/(n - 1)$$

$$\text{In this example: CI} = (3.131 - 3)/(3 - 1) = 0.068$$

It is important to note that  $\lambda_{\max} > n$  resulting in CI to always be non-negative.

4. The Consistency Ration (CR) is calculated as a ratio of the CI to the “Mean Random Consistency Index (MRCI)”. The MRCI is the expected value of CI for matrices that has a size of  $n \times n$ , positive, reciprocal and their elements are taken at random from the scale  $\frac{1}{9}, \frac{1}{8}, \frac{1}{7}, \dots, \frac{1}{2}, 1, 2, 3, \dots, 8, 9$

The following table of MRCI's was calculated by Saaty and is being used as benchmark:<sup>9</sup>

**Table 2: Table of Mean Random Consistency Indices**

n	1	2	3	4	5	6	7	8	9	10
MRCI	0	0	0.5245	0.8830	1.1085	1.2493	1.3405	1.4042	1.4511	1.4857

In this example:  $CR = 0.068 / 0.5245 = 0.13$

In this example it may be worthwhile to re-evaluate the pairwise comparisons and relative weights allocated.

### 4.3 Determination of Priority Vectors

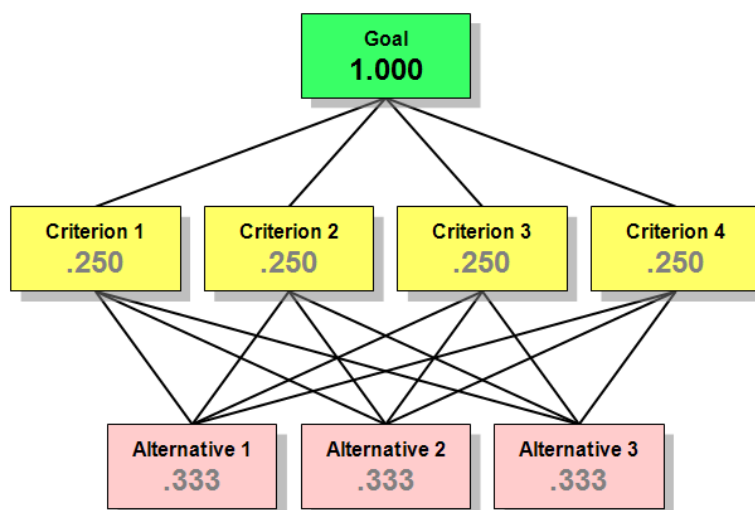
Priorities are values associated with the alternatives within an AHP hierarchy. They denote the weights of importance of the different alternatives relative to each other for a specific criterion.

It is important to note that the sum of the priorities for the criteria should be 1. The same is true for the sum of the priorities of the alternatives.

It is furthermore also important to note that priorities are always absolute numbers between zero and one and does not have any units.

In essence, an alternative with a priority of 0.4 carries twice as much weight for a specific criterion than another alternative with a priority of 0.2 for the same criterion.

The ideal AHP hierarchy in an ideal mode is shown in figure 1<sup>10</sup>



**Figure 1: Hierarchy of AHP-levels**

The calculated hierarchy of priorities will enable the user of this optimisation process to focus on those alternatives (components) that will have the most significant influence.

The different relative weights of the final priorities for an M x N-matrix are calculated by the following formulae:

$$P_i = \sum_{j=1}^N a_{i,j} W_j \text{ for } i = 1,2,3... M$$

Where: P = Priority

a = weight of alternative j

W = weight of corresponding criterion j

In practise, various software programmes like *Expert Choice* have been written to automate the process of prioritisation.

Utilising software has various advantages including faster analysis and the possibility to evaluate the effect the weights allocated during the pairwise comparison will have on the Consistency Ratio if the latter is above 10%.

#### **4.4 Important factors to keep in mind when using the AHP<sup>11</sup>**

##### ***1 The Uniqueness of the solution***

The concept of the AHP lies in the fact that different alternatives are all tested against each other on a “fair” or objective basis. Since the analysis and grading of the relative preferences are done by humans, it may however happen that the pair-wise comparisons result in a conundrum where the associated matrix becomes degenerate. This is found especially where extremely strong favour is given to one alternative against another, for instance:

Test	Intensity/Weight
A is better than B	9
B is better than C	9
C is better than A	9

This produces the following matrix:

	A	B	C
A	1	9	$1/9$
B	$1/9$	1	9
C	9	$1/9$	1

Though common sense suggests that such a situation is impossible, due to human factor in the scoring of the pairwise-comparisons, it is likely to happen.

## ***2 The risk of Rank Reversal***

The risk of rank reversal is normally associated with the addition or removal of an alternative. Rank Reversal has the effect that, due to one of these two actions mentioned, the order of preferences of the alternatives may change.

This means that the basis for decision-making on the grounds of the ranking developed previously may prove to be unstable once the number of alternatives is changed.

This may make it difficult for the user to explain and buy into the concept of ranking as the rank of an alternative might change from time to time as considerations are modified.

Rank-reversal may not necessarily result if an alternative is added or removed, but the possibility increases considerably.

Though a change in numbers cannot be excluded at all costs, as this will make the system unnecessarily rigid, a proper in-depth analysis of all the alternatives at the on-set decreases the unnecessary alteration of the Level 3-elements (or alternatives).

## **4.5 Group Decision Making**

The Analytic Hierarchy Process in itself is a tool that can be utilised to assist the decision-maker in determining the order in which attention should be given to different alternatives.

The next question that needs to be addressed is who the decision-maker is. In the Airport Management set-up there are different portfolios that focus on the same



airport but with different intent. It is typical that at least the following portfolios will be represented at an airport:

- **Operations:** This division is responsible for the day-to-day running of the airport ensuring a safe and efficient facilitation environment.
- **Maintenance:** This division is responsible for the continuous monitoring of the different infrastructural systems at the airport ensuring that it is kept in a safe working condition.
- **Commercial Services:** This division is responsible for the development of the airport as a business unit thereby ensuring a cash flow *into* the airport.

Except for the three mentioned above there may be other portfolios also contributing to the airport environment. It is therefore safe to say that the focus of the decision making will depend largely on the portfolio responsible for the decision making. It may very well be that the main focus of the Commercial Services Division will be on the upkeep of commercial areas whilst the Maintenance Division would like to place emphasis on the upkeep of infrastructural services.

To overcome this obvious obstacle, it will be best to create a “*decision maker*” consisting of a committee of representatives of all the relevant portfolios. This will increase the probability of a more accurate, and representative, outcome to the decision-making effort. The individual decisions of the group-members will therefore need to be synthesized to allow for a single, recordable decision.

Arrow proved with his Theorem of Impossibility<sup>12</sup> that it is important that all the following conditions be adhered to by the aggregation procedure to allow for a rational group choice:

- *Decisiveness:* The aggregation procedure must allow for a group order to be developed. In other words, all the members of the group should make a choice and decision on each question.
- *Unanimity:* If all individuals in the committee prefer Alternative A to Alternative B, then the aggregation procedure must produce a group-decision indicating that the group prefers Alternative A to Alternative B.
- *Independence of Irrelevant Alternatives:* If both options A and B are included in two different alternatives, and Option A is always preferred to Option B, the aggregation procedure must produce a group-decision indicating that Option A is preferable to Option B.

- *No Dictator*: NO single individual's decision may take preference in the group.

When one aggregates individual judgements, there are five conditions that must be true both for the individual scores and the aggregated scores.<sup>13</sup> If one assumes the function of synthesized judgments is  $f(x_1; x_2; \dots x_n)$  for  $n$  judgements, then the following should be true:

- *Separability Condition (S)*:  $f(x_1; x_2; \dots x_n) = g(x_1)g(x_2) \dots g(x_n)$  for all  $x_1, x_2 \dots x_n$  in an interval I of positive numbers, where  $g$  is a function mapping I onto a proper interval J and is a continuous, associative and cancellative operation.

Condition (S) implicate that the influences of the separate judgments can be separated as above.

- *Unanimity Condition (U)*:  $f(x_1; x_2; \dots x_n) = x$  for all  $x$  in I.  
(U) implies that if all individuals gave the same judgement  $x$ , that the synthesized judgement should also be  $x$ .

- *Homogeneity condition (H)*:  $f(ux_1; ux_2; \dots ux_n) = u f(x_1; x_2; \dots x_n)$  where  $u > 0$ .

(H) implies that if all individual judgments are  $u$  times larger, the synthesized judgement should be  $u$  times larger.

- *Power Condition (P<sub>p</sub>)*:  $f(x_1^p, x_2^p, \dots x_n^p) = f^p(x_1; x_2; \dots x_n)$ .  
(P<sub>p</sub>) may for illustration imply for instance that the synthesized judgement on the area of a square be given by the square of the synthesized judgement of the length of that square.

- *Reciprocal Property (R)*: (R) is a special condition of (P<sub>p</sub>) where  $R = P_{-1}$  i.e.

$$f\left(\frac{1}{x_1}, \frac{1}{x_2}, \dots, \frac{1}{x_n}\right) = \frac{1}{f(x_1, x_2, \dots x_n)}$$

It was then proved by Aczél and Saaty that the only aggregation procedure where all the conditions are adhered to is the *geometric mean* of the judgements<sup>14</sup>.

In other words, the synthesized judgment of a group decision for a specific criterion reads:

$$f(x_1; x_2; \dots x_n) = \sqrt[n]{x_1 x_2 \dots x_n}$$

# Chapter 5 – Analysis for Optimisation of Components

The AHP is used as a method to establish a hierarchy of infrastructure-related components that can be optimised.

## 5.1 Identification of the elements of the different levels

With reference to Chapter 4 it is therefore apparent that the following points should be established to allow for the accurate analysis and determination of the optimisation hierarchy:

Level 1: What is the objective?

Level 2: What are the attributes that influence the objective?

Level 3: What are the various alternatives (components) that are influenced by the attributes?

### Level 1

The objective of the study is to determine the hierarchy in respect of optimisation potential of the different components of a small airport.

### Level 2

In the case of small airports there are three attributes that need to be considered during the optimisation process. These three qualities are relevant parts of each component and need to be considered at all times. The attributes are:

#### *Safety*

- Safety Impact (SI)

This attribute concerns the issue if, and to what extent, a specific component may **directly** influence the safety of the airport. Although it may theoretically be possible to have infrastructure that is operational but not adhering to the minimum safety standards, it is not acceptable by international standards.

#### *Financial Streams*

- Revenue Potential (RP)

This element describes all components that may be used to generate an income, directly or passively, to the operational authority. It may be that, at

the current stage, the revenue generation is dormant but it is important to identify potential income sources.

### *Maintenance*

- Maintenance Liability (ML)

This attribute is the most obvious and easiest to quantify. It is imperative to know the exact maintenance cost of any component to ensure an acceptable lifespan of such a component.

It is important to note that replacement value of the component is not being assessed. The replacement cost should not be confused with the operational cost of a component as it always requires a capital outlay from the owner. The main reason why this clear distinction is made specifically in the case of small airports is the extremely high costs associated with the replacement of some infrastructure, e.g. the runway. It is normal that the revenue generated at these small airports will not be sufficient to cover the premiums of such major capital developments and that these expenses be dealt with using by-mechanisms such as cross-subsidization or third-party finance e.g. government bail-outs.

Part of this step is finding the relative importance or weight (W) of these three criteria relative to each other by doing pairwise comparisons of them and then establishing the criteria-priority vector. (Refer to 4.2 (1) for explanation of establishing the priority vector.)

### **Level 3**

In this level all the sub-systems that need to form part of the list of infrastructure, ranked according to its optimisation potential, is identified.

Once the all the required information was determined and the AHP was used to determine the hierarchy of components that need to be addressed, the analyst can move on to the optimisation-phase.

## 5.2 Framework of the Optimisation Model

The optimisation process itself will be done through the set-up of a prescriptive model in the form of an optimisation model. Being a prescriptive model, the following three components need to be clearly identified for each component separately:

- The Objective Function  
This is the main function of the optimisation effort. It will either be to minimize or maximize the objective function linked as an aspect of a specific system component.  
It is possible to have a *multiple objective decision making problem* where the final objective for a certain component may have to satisfy two different objectives.  
Most infrastructural optimisation efforts for smaller airports tend to be simple, single objective problems.
- The Decision Variables  
Decision Variables are those values that influence the performance of the system. It is these variables that will be changed to reach the optimised goal that is the objective function.  
Variables can be divided into two categories namely dependent- and independent variables.  
Independent Variables are those variables that can be manipulated and changed whilst the Dependent Variable are those that are affected by the changes. For illustrative purposes one can make the correlation to traditional Calculus with  $y$  (Dependent Variable) =  $f(x)$  where  $x \Rightarrow$  Independent Variable.
- The Constraints  
These are the restrictions of the abovementioned variables outside which these variables cannot fall.

The optimisation-process for infrastructure can generally be understood as the answering of the following four questions:

- What is the calculated capacity of my infrastructure?
- What is the *current* required capacity for that infrastructure to enable the provision of an acceptable level of service?
- What is the *forecasted* required capacity for the infrastructure for a given time-horizon?
- What optimisation model can be used to provide the optimum final result?

### 5.3 Calculating the Capacity of Infrastructure

The capacity-calculation of infrastructure depends on the particular type of infrastructural component under consideration.

This is due to the fact that the influences or decision variables differ from component to component. The same basic engineering design principles used for capacity analysis during the development of a component need to be used for the analysis of that component's future capacity.

The type and size of aircraft that is due to use a runway plays a considerable role in calculating the length and width during the design phase of that runway.

The sizing of a terminal building, as well as the different components that will be accommodated in the building, will *inter alia* be dictated by the required "Level of Service". The "Level of Service"-system is used by analysts to determine or describe the effectiveness of specific infrastructure.

### 5.4 Current Capacity Demand

With specific reference to Chapter 1, it is highly probable that the current utilisation of an infrastructural component at a small airport is not being utilised to its full capacity. It is however important to know exactly how the current demand correlates to the available capacity. As demonstrated in Figure 2, is this point being used as the reference/basis point for future capacity calculations.

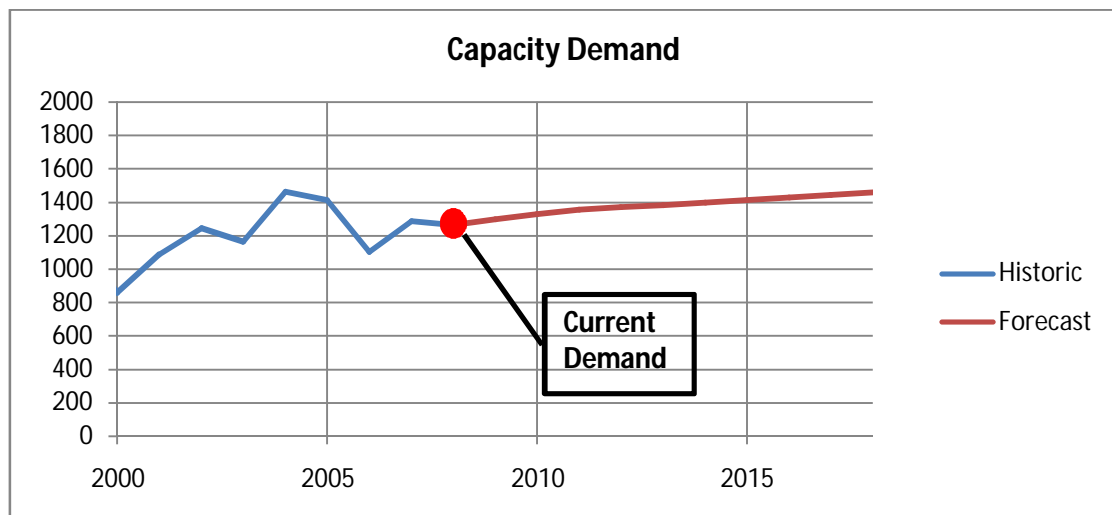


Figure 2: Historic data vs. Forecast

## 5.5 Future Capacity Demand

To enable one to make an accurate estimate of the future capacity requirements it is necessary to make a forecast of the expected demand based on the historic data available.

### 5.5.1 Forecasting Methods

Two of the most frequent utilised forecasting methods<sup>15</sup> to derive at an estimated future demand are:

- *Simple Linear Regression or Extrapolation Method*

This model uses historic values and relationships between dependent- and independent variables to derive at a representative mathematical model. This model is then used as basis for forecasting future values. This method assumes that historic patterns and trends will be repeated in future.

This method is normally used on data that is collected over an extended period of time where deviations from the mathematic model have a limited effect.

A good example will be the world population growth from the 1950's until today which seem to follow a persistent pattern despite numerous droughts, wars and other phenomena that, at first glance should have had a significant influence on the world population.

- *Casual Forecasting Method*

In cases where the historic data is frequently influenced by external factors (or independent variables) it may first be necessary to calculate the relationship of these factors on the dependent variable before that variable is utilised in a mathematical model used in forecasting.

This method is used where it is important to acknowledge those factors that “caused” the historic values which are to be used as basis for the forecasting model.

This method is used on data that is recent and “fresh” as well as data that tends to be significantly influenced by external factors.

A good example where this method will be used is to determine the forecasted sales of a product, knowing that it was significantly influenced in the past by factors such as price and advertisement.

### 5.5.2 Regression Analysis

Regression Analysis implies the prediction of the value of a dependent variable by changing the independent variable after the analysis of the historic relationships between the variables.

This can be done by determining a simple linear regression<sup>16</sup> representing the least square regression line that best fit the plotted values. This line is represented by the following formula:

$$\hat{y} = \hat{\beta}_1 x + \hat{\beta}_0$$

Where:  $\hat{y}$  = the Predicted  $y$  value

$$\beta_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

$$\beta_0 = y - \hat{\beta}_1 x$$

$\bar{y}$  = Average of  $y$

$\bar{x}$  = Average of  $x$

$x_i$  = Measured Independent Variable

$y_i$  = Measured Dependent Variable

The determination of the regression line can be done automatically by software like Microsoft® Excel or Minitab. The software will also automatically calculate the regression formula for the represented line chosen by the analyst and allows one to obtain more than one possible regression formula.

The analyst therefore need some measure to determine which of the different potential options will be the best representative regression formula.

### 5.5.3 Determining the Best Fit

To determine which one of the potential regression formulae will best represent the real values and should be used for forecasting, it is first necessary to examine three components of variation:

- Sum of Squares Total (SST)  
The SST measures the total variation of  $y_i$  about its mean.  
$$SST = \sum(y_i - \bar{y})^2$$
- Sum of Squares Error (SSE)  
The SSE gives an indication of the Error (or “noise”) between the predicted values and the real, measured values.  
Hypothetically, for a perfect fit:  $SSE = 0$   
$$SSE = \sum(y_i - \hat{y}_i)^2 = \sum e_i^2$$



- Sum of Squares Regression (SSR)

$$\begin{aligned} \text{The SSR} &= \text{SST} - \text{SSE} \\ &= \sum(\hat{y}_i - \bar{y})^2 \end{aligned}$$

The degree of fit can then be determined by the *Correlation Index* ( $R^2$ ). This index represents the non-dimensional ratio of the SSR to the SST. It can also be described as the percentage variation in  $y$  explained by  $x$ .

$$R^2 = \text{SSR} / \text{SST}$$

As an example: if  $R^2 = 0,95$  (or 95%) for an analysis where the independent variable is the IQ (Intelligence Quotient) and the dependent variable is a studied subject's test-results, it means that the IQ will be responsible for 95% of the variance whilst any other factors will have a combined influence of 5%.

It can therefore be seen that, the closer the  $R^2$ -value is to 1 (or 100%), the stronger the correlation between the two variables.

#### 5.5.4 Accuracy of the Forecast

It is possible that, through analysis, a very strong correlation is obtained. It is however still important to ascertain the forecasting accuracy of the regression analysis. The *Standard Error of the Estimate* ( $s_e$ ) can be calculated by the following formula:

$$s_e = \sqrt{\frac{\text{SSE}}{n - 2}}$$

Where:  $n$  = the number of observations.

It is important to know that any measured value for  $y_i$  which is not within  $2 s_e$  of  $\hat{y}_i$ , is normally considered an **outlier**.

These outliers need to be investigated to understand why they resulted and what their specific significance and influence is on the overall forecast.

A typical example of an outlier is the drastic reduction in air-traffic during the period immediately following the September 11-attacks on the United States of America.

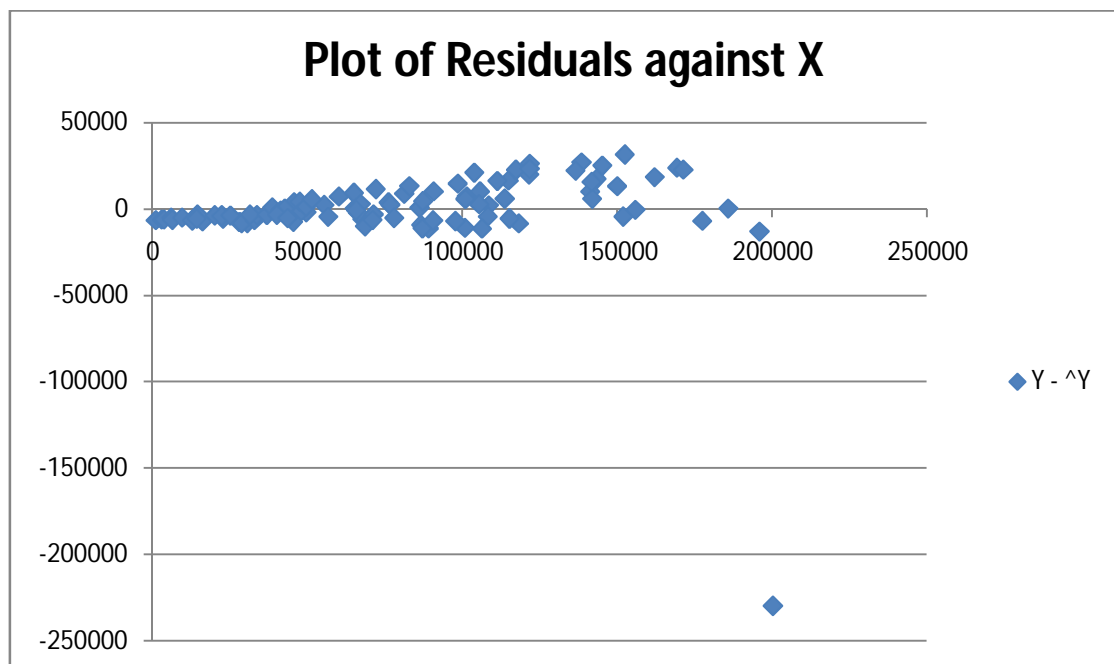
### 5.5.5 Supportive Assumptions<sup>17</sup>

There are three key underlying assumptions which need hold true in order to use simple linear regression. These assumptions are rarely tested in reality and it is normally only once inconsistent results are obtained that an analysis of the data, as well as the inter-dependency thereof, is investigated.

#### *Assumption 1: Homoscedasticity*

The concept of homoscedasticity implies that the samples analysed were selected at random from a population of interest.

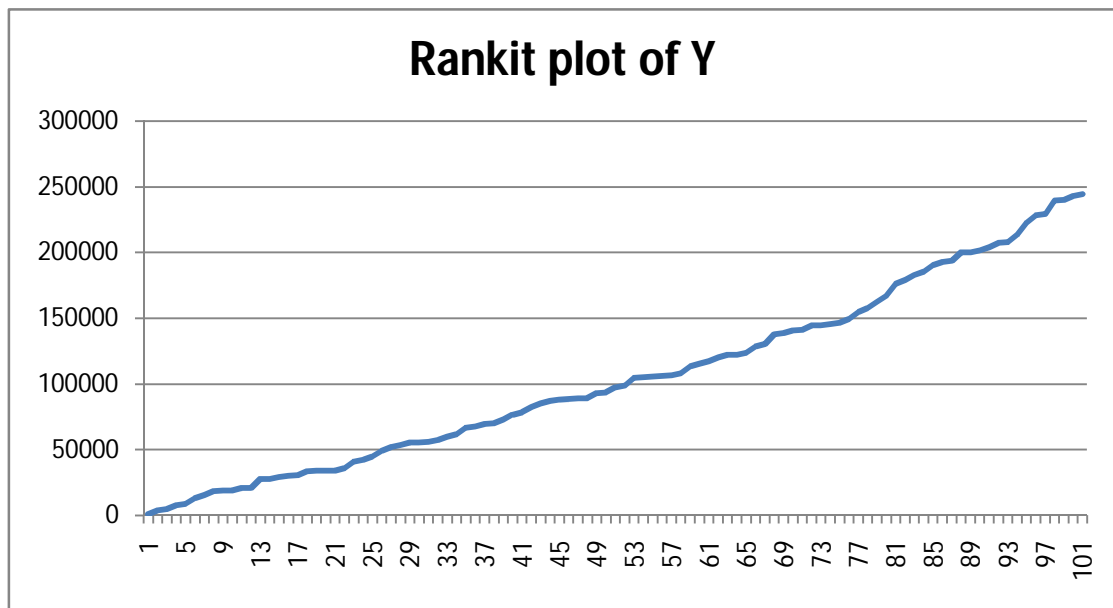
This is to ensure that the variance of the error term is independent of the independent variable ( $x$ ).



**Figure 3: Plot of Residual Values vs. Independent Variable**

A typical plot of data distribution as depicted above shows no apparent relation between the residuals and the independent variable indicating that the dependent variables are random without any underlying relationship between themselves.

*Assumption 2: Errors should be normally distributed*

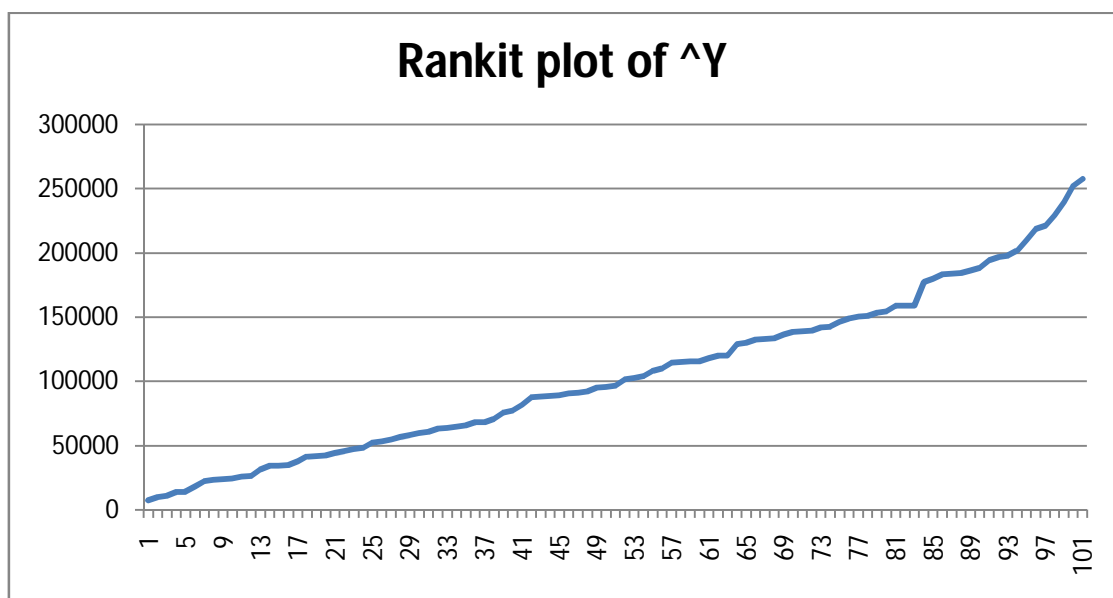


**Figure 4: Rankit plot of Dependent Variables**

This plot shows an almost straight line of the Rankit-plot of the dependent variable which is indicative of a normal distribution

*Assumption 3: Errors should be independent*

The error terms (or deviations) should follow identical and independent normal distributions, i.e. the *error* term should not statistically depend on the values of the independent variables



**Figure 5: Rankit plot of Predicted Dependent Variables**

A plot as shown above follows an almost straight line of the ordered response/predicted values ( $\hat{Y}$ ) if plotted as a *Rankit*-model which is indicative of a normal distribution of the error terms.

## 5.6 Optimisation Process

Once one has the current demand and forecasted capacity requirements available, it is possible to optimise the infrastructural component under consideration using the capacity-values as model constraints.

### 5.6.1 Optimisation Models

Different approaches can be taken in the optimisation procedure mainly depending on whether a process or attribute of a physical infrastructure component needs to be analysed.

Various optimisation-models can be used for, or were developed on, operational-components, i.e. the “streamlining” of operations. Some of the most commonly used models are:

- Travelling Salesman (Shortest Path) Model:  
This model is based on the concept that a salesman that needs to travel between cities would like to find the shortest route, therefore the fastest route, possible to cover all cities.  
This model can be used as a route-optimisation tool for ground-handlers or any system with more than one criterium that need to be met.
- Transportation & Trans-shipment Models:  
The movement of stock from a supply point, directly or indirectly, to a demand point can be modelled using these two types of models.
- Work Scheduling Models:  
This model is used to find the optimal solution to the scheduling of a work force, or resources, to fit a variable demand.

The optimisation of infrastructure can be done in one of two ways.

One can *firstly* define a Linear Programming Model, complete with Decision Variables and Constraints clearly identified. This can be transformed into a mathematical model and can then be evaluated accordingly.

The *second* alternative is a more graphical approach. This involves the plotting of the relevant information on a graph, both historic and forecasted, and then to do a physical read-off of required values.

Rather than having to choose one of the two approaches, it is recommended that the analyst uses, where applicable, both alternatives simultaneously, two of the main reasons being:

- The first alternative generates one more accurate mathematically-calculated results and if one uses programmes such as *SPSS*® (Statistical modelling and analysis), *Lindo/Lingo*® (Linear programming) or *MS Excel*® (Spreadsheet Analysis) it may automatically perform a sensitivity analysis on the data, calculate the standard deviations and provide the analyst with an ANOVA (Analysis of Variance). This data then forms the foundation of the regression analysis of any data set.
- Since the concept of optimisation of infrastructure will most probably need to be “sold” to the management of the airport authority, it will also be worthwhile to do a graphic representation of the scenario at hand. In that way the decision-makers can get a visual representation of the Optimisation Model.

It is sometimes sufficient to only use one of the two aforementioned approaches thereby not over-complicating the optimisation-process.

*It is important to realise that the optimisation-process is not a hunt for the Holy Grail with a mathematically calculated result that needs to be implemented at all costs. It is rather a very strong compass to be used as a guideline to improve the existing conditions.*

### 5.6.2 Sensitivity Analysis

Equally as important as the accurate regression analysis of a data set, is the analysis of the sensitivity of the outcome of the regression analysis to changes to the variables, parameters or base-conditions.

The analyst can use the product of the regression analysis of a data set as basis for forecasting. The analyst therefore makes the assumption that the regression will hold

true for all future data ranges as it did for historical data ranges. This forecasting is then used to obtain the optimal solution for a component.

It is however obvious that, should the basis for the assumptions used [the independent variables and Linear Programming (LP)-parameters] change, that there will also be a change in the forecast and therefore also in the end-result or optimum value.

The analyst therefore has to indicate, along with the optimised value, how sensitive that value will be for any changes to the historic independent variables and parameters. This will allow the analyst to test the outcome of different scenarios.

Only once all of the above criteria have been satisfied and/or accounted for can the analyst make a clear, quantified recommendation to the client or management.

## Chapter 6 – Case Study: Katima Mulilo Airport



Figure 6: Location and Layout of Katima Mulilo Airport

## 6.1 Background

Katima Mulilo is located in the North Eastern corner of Namibia close to the borders of Botswana, Zambia and Zimbabwe. This location is of strategic importance to the country as a whole and the airfield, then known as Mpacha-airbase, was developed as a forward logistics base during the military conflict in Namibia during the 1970's and 1980's.

The conflict ended with the Independence of Namibia in March 1990, after which time the airport was utilised for commercial purposes and became known as Katima Mulilo Airport (ICAO Code: FYKM)

## 6.2 Goal

Even at first glance it is evident that there might be superfluous infrastructure in existence at the airport, considering its new civilian application. There is, for instance, a full-length taxiway, four taxiway – runway intersections and a rather large aircraft parking apron. All this infrastructure relates to the previous military requirement to vacate aircraft fast from the runway and to have sufficient parking space. Since we know it is a small airport, with light traffic, it is deemed worth investigating if it is not possible to go through an optimisation-process in order to bring the infrastructure in line with the actual and predicted future demand.

**The final goal is to optimise the infrastructure of the airport in order to reduce expenses without compromising safety or security.**

The goal for the AHP-exercise will therefore be *to establish the hierarchy of priority of the sub-systems to be optimised.*

The analysis will therefore be divided into two distinct parts. Part I will be the application of the AHP for identification and ranking of the decision attributes. Part II will be the optimisation analysis in the order prescribed by the AHP.

### *PART I – IDENTIFICATION OF DECISION ATTRIBUTES WITH THE AHP*

## 6.3 What are the determining attributes (Level 2-criteria)

As previously identified, the three attributes to be considered in this study are:

- Safety
- Revenue Potential
- Maintenance Liability



A decision-making committee made up of representative individuals decided that the relative importance of these three attributes for the Katima Mulilo Airport are:

	<b>Safety</b>	<b>Revenue Potential</b>	<b>Maintenance Liability</b>
<b>Safety</b>	1	7	2
<b>Revenue Potential</b>	$\frac{1}{7}$	1	$\frac{1}{6}$
<b>Maintenance Liability</b>	$\frac{1}{2}$	6	1

From the above it is clear that e.g. Safety is regarded as of *Demonstrated More Importance* (7) than Revenue Potential

Software such as *Expert Choice*® requires the user to assign the weight to the stronger value in an effort to make the product more user-friendly. The transformation of value is done as part of the operating algorithm.

Based on the above values, the calculated priority vector is therefore:

(0,582; 0.069; 0,348) (Safety, Revenue Potential, Maintenance Liability)

## 6.4 Preliminary Selection

In order to establish those sub-systems that will be eligible for optimisation, we first need to do at the preliminary selection eliminating those sub-systems that will have little or no influence and those sub-systems that are not under the jurisdiction of the Aerodrome Operator.

**Figure 7: Provisional Selection of sub-systems for Katima Mulilo Airport**

No.	SUB-SYSTEM DESCRIPTION	INCLUDED IN ANALYSIS		REASON, IF EXCLUDED
1	Passenger Management	√		
2	Ground Handling	√		
3	Security	√		
4	Meeters- & Greeters Management	√		
5	Landside Vehicle Management	√		
6	Runway, taxiways and apron areas	√		
	Air-traffic control (ATC)		X	Air traffic control is not under the jurisdiction of the Aerodrome Operator
7	Hangars and Hardstand Areas	√		
	Immigration control, Customs & Excise		X	Immigration, Customs & Excise is governmental agencies and not under the jurisdiction of the Aerodrome Operator
	Airport Rescue & Fire-fighting (ARFF)		X	The ARFF at this airport is at the lowest category. It is therefore impractical to address it.

## 6.5 AHP: Pairwise Comparisons

The results of the committee's pairwise comparisons in relation to the different attributes are reflected in the matrices below:

One of the committee-member's results is presented in Addendum 1.

Screenshots from *Expert Choice*® shows the relative weights that were assigned by the committee during the comparison effort.

## Safety

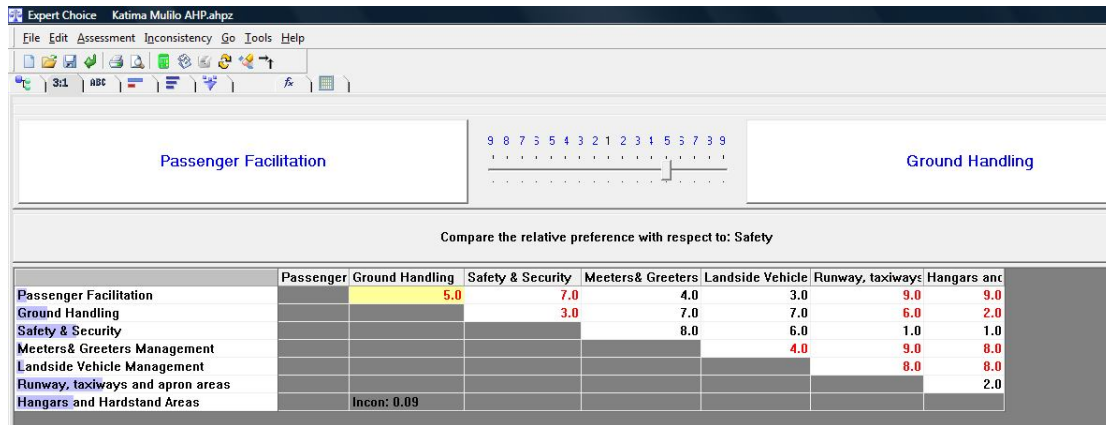


Figure 8: Pairwise Comparison Input for Safety

## Revenue Potential

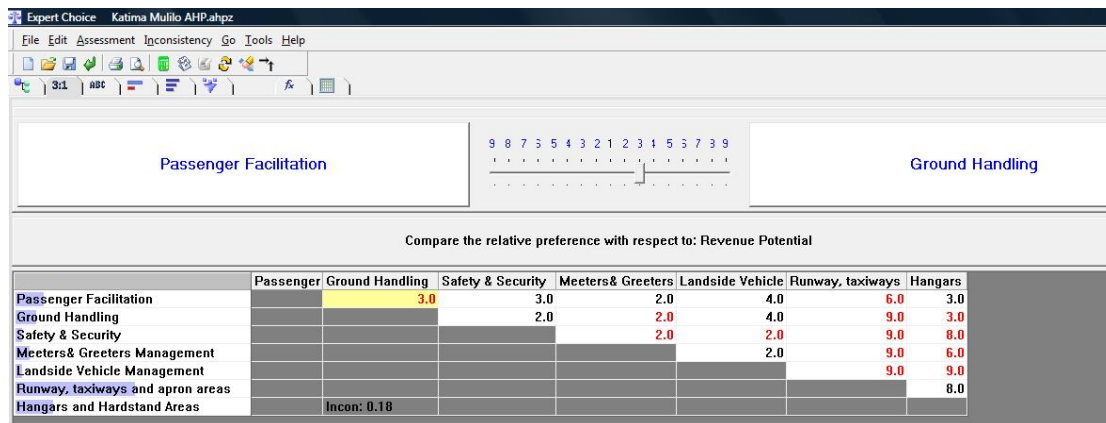


Figure 9: Pairwise Comparison Input for Revenue Potential

## Maintenance Liability

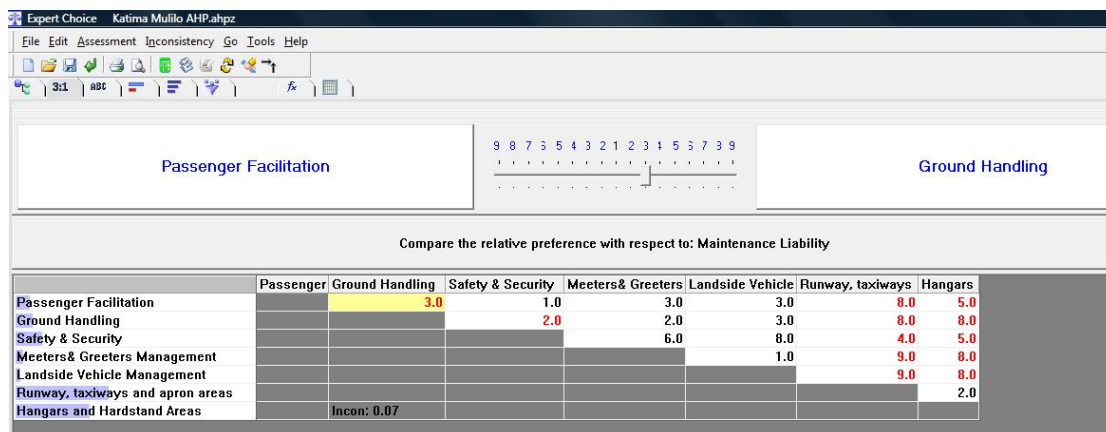


Figure 10: Pairwise Comparison Input for Maintenance Liability

As an example, the associated matrix for Maintenance Liability would look as follows:

**Figure 11: Matrix of Pairwise Comparisons of Maintenance Liability**

<b>Maintenance Requirements</b>	Passenger Facilitation	Ground Handling	Safety & Security	Meeters & Greeters Management	Landside Vehicle Management	Runway, taxiways and apron areas	Hangars and Hardstand Areas
Passenger Facilitation	1	1/3	1	3	3	1/8	1/5
Ground Handling	3	1	1/2	2	3	1/8	1/8
Safety & Security	1	2	1	6	8	1/4	1/5
Meeters & Greeters Management	1/3	1/2	1/6	1	1	1/9	1/8
Landside Vehicle Management	1/3	1/3	1/8	1	1	1/9	1/8
Runway, taxiways and apron areas	8	8	4	9	9	1	2
Hangars and Hardstand Areas	5	8	5	8	8	1/2	1

## 6.6 AHP: Results of Pairwise Comparison of Alternatives

If one synthesizes the comparisons done, as indicated above, with Expert Choice ®, the output values can be seen in the following screen-shots.

Hierarchy of importance with regard to **Safety**:

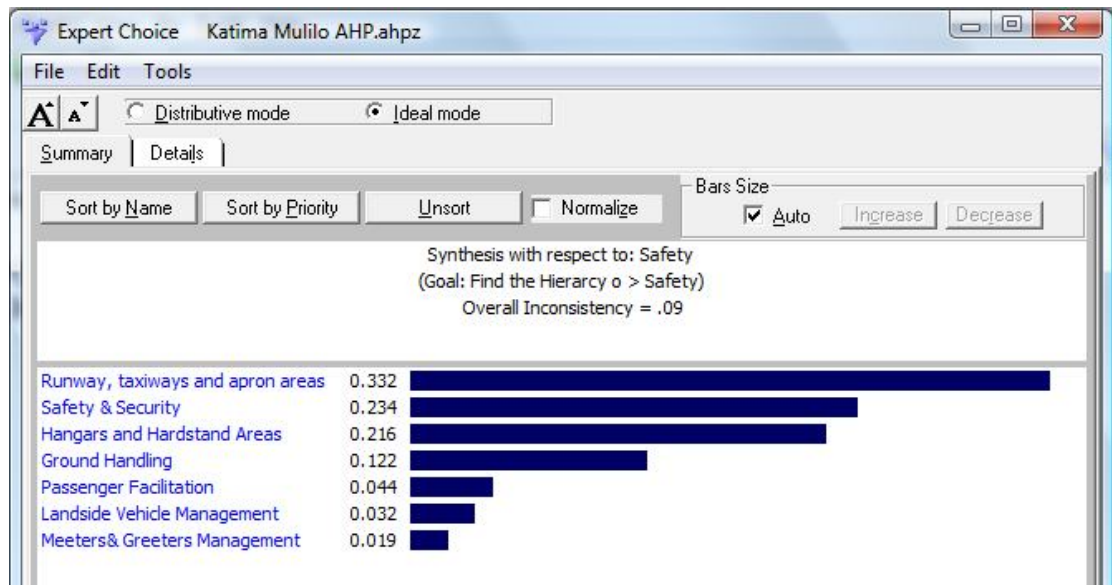


Figure 12: Synthesised Priority Vector in respect of Safety

Hierarchy of importance with regard to **Revenue Potential**:

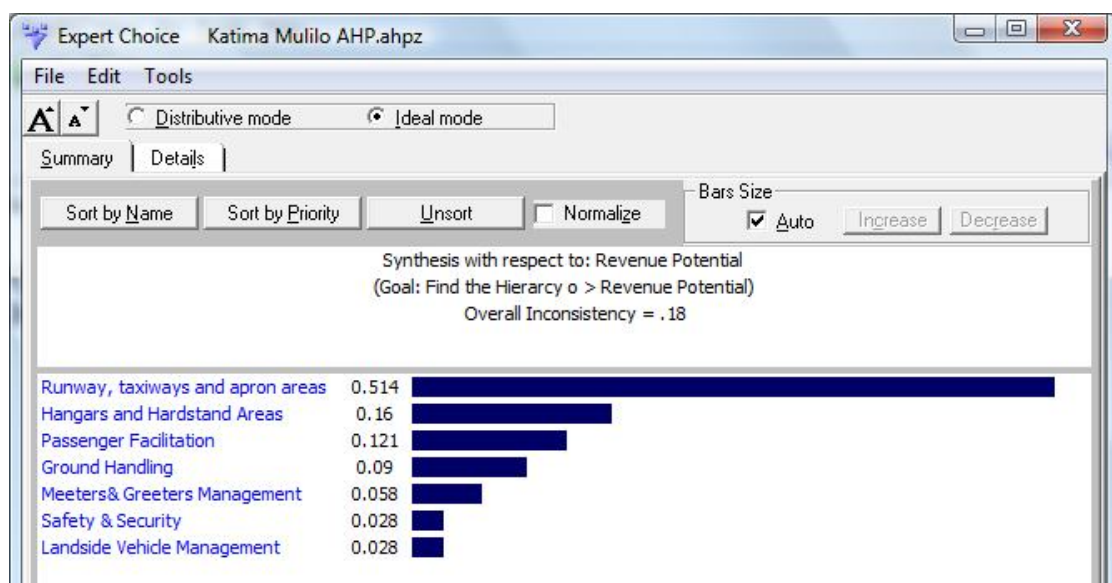


Figure 13: Synthesised Priority Vector in respect of Revenue Potential

Hierarchy of importance with regard to **Maintenance Liability**:

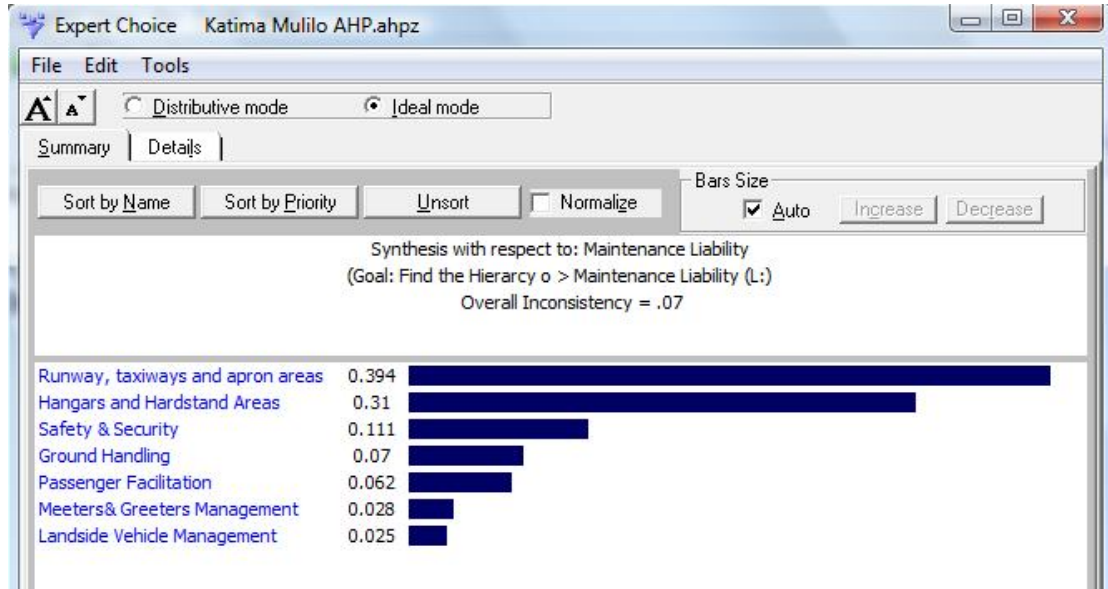


Figure 14: Synthesised Priority Vector in respect of Maintenance Liability

Hierarchy of priorities with regard to **the Goal**:

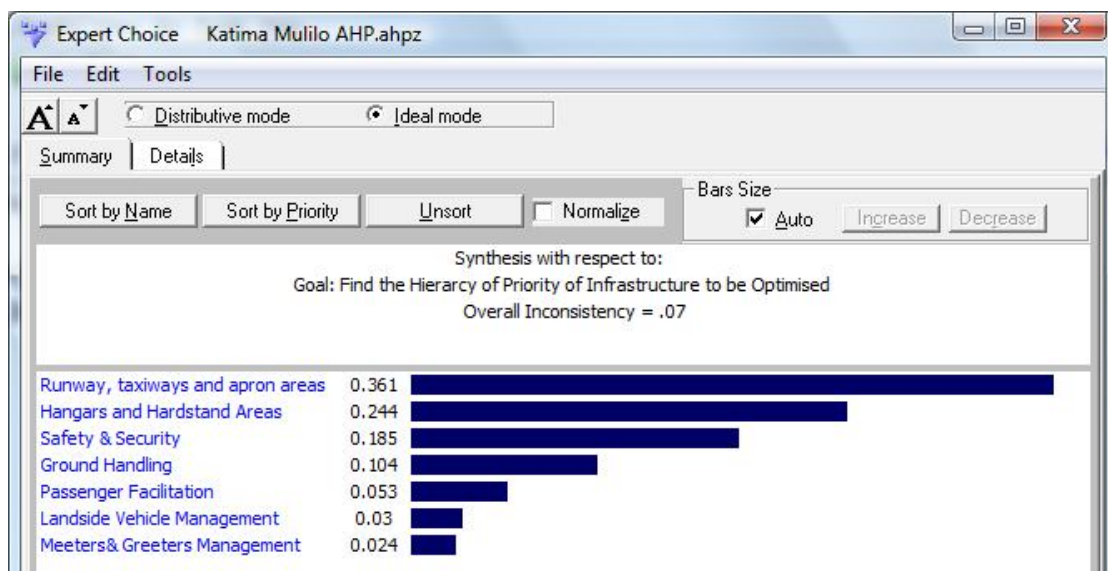


Figure 15: Synthesised Priority Vector in respect of the Goal

A normalised view of the synthesis in respect of the goal results in the following graph:

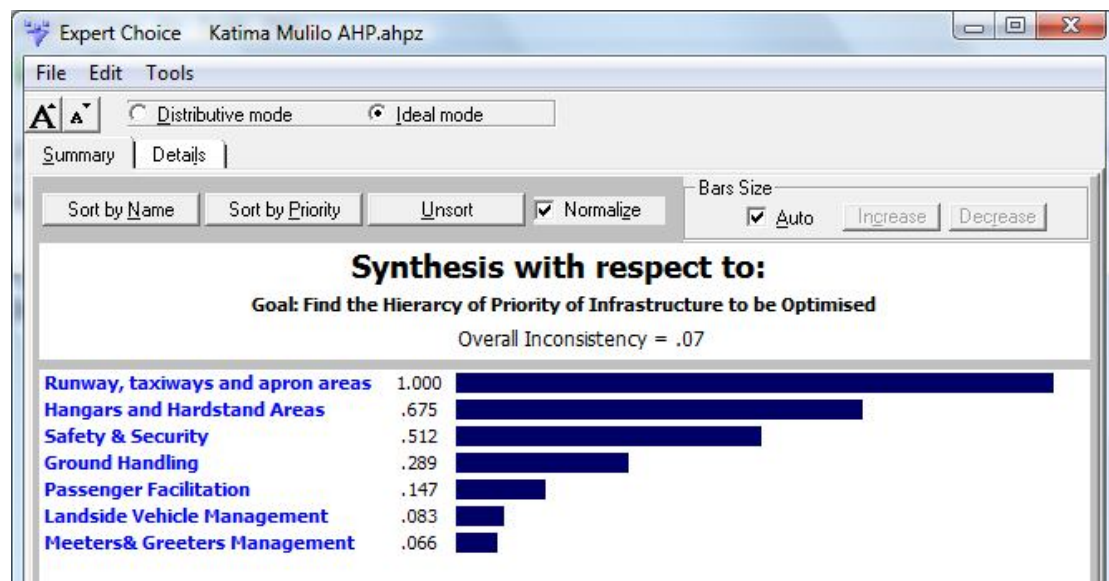


Figure 16: Normalised Priority Vector in respect of the Goal

From this graph, one can derive at the following conclusions:

1. The runway, taxiways and apron areas have the most important influence in respect of *Maintenance*, *Revenue potential* and overall *Safety*. Changing the components of this sub-system will have the most influence on the mentioned three attributes.
2. The **Runway** sub-system has almost twice as much influence on the three attributes as the **Safety & Security** sub-system.
3. Any changes to the Meeters- and Greeters area will have the least influence in respect of the three attributes and may be considered to be a waste of resources.
4. The overall inconsistency (Cr-value) is 0.07, viz. lower than 10%, making this a representative and acceptable model.

## 6.7 AHP: Sensitivity Analysis

*Expert Choice*® also calculates sensitivity gradients for each attribute. This enables the analyst to determine the stability of the final results obtained if the original weight of the attribute (as determined under section 6.3) should change.

Screen-shots of the three graphs, with the x-axis a sliding scale of the attribute's priority in respect of the priority vector, are:

### Colour Legend

Runway, Taxiway and Apron Areas

Passenger Facilitation

Hangars and Hardstand Areas

Ground Handling

Safety & Security

Landside Vehicle Management

Meeters- and Greeters Management

### For Safety

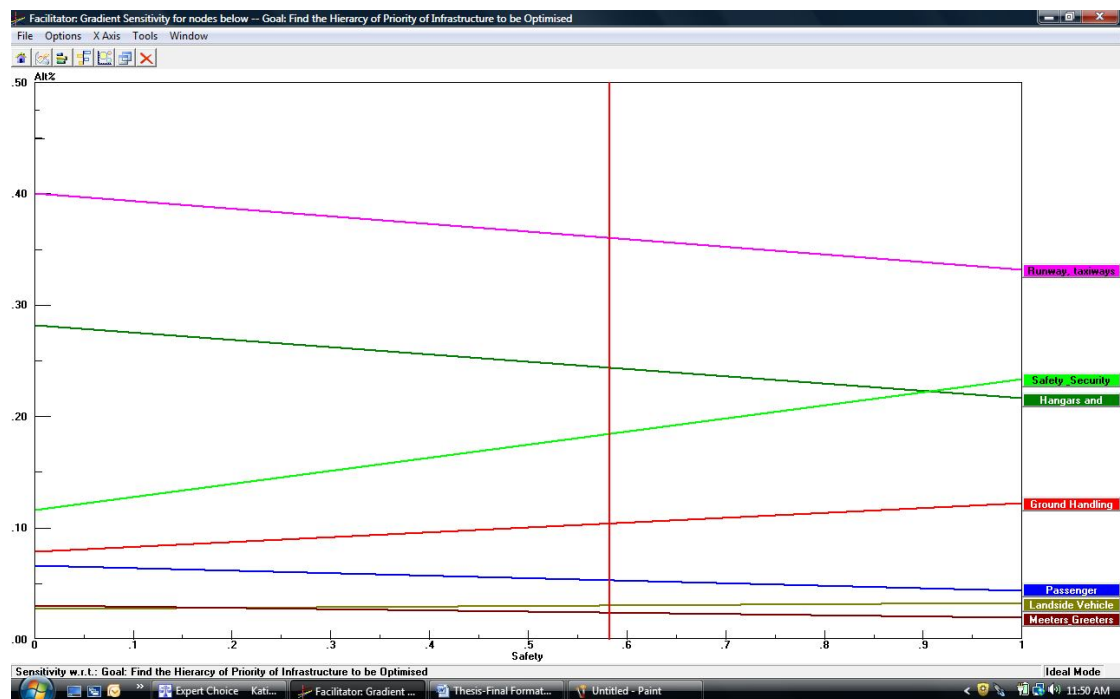
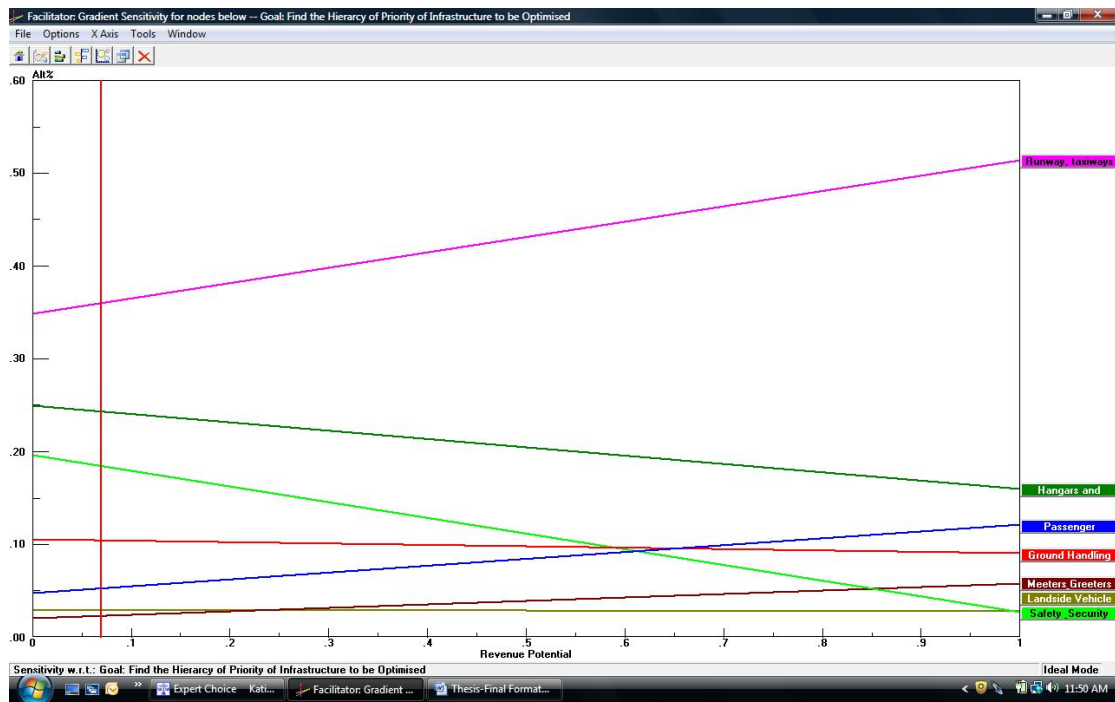


Figure 17: Sensitivity Graph in respect of Safety

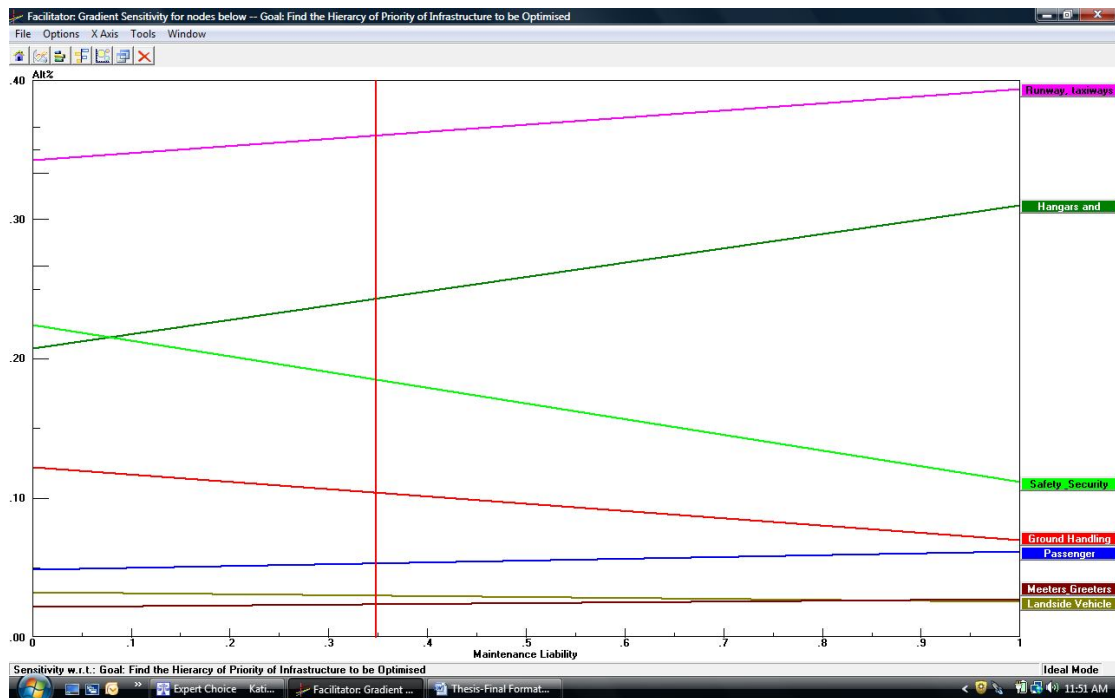


*For Revenue Potential:*



**Figure 18: Sensitivity Graph in respect of Revenue Potential**

*For Maintenance Liability*



**Figure 19: Sensitivity Graph in respect of Maintenance Liability**

It is evident from the three graphs that, even should the priority of the three attributes change, the *Runway, Taxiway and Apron Area* sub-system will still have the most influence.

This is followed, for most of the time, by the *Hangers and Hardstand Area* sub-system.

Based on the foregoing, the analyst can feel confident to move to the next step which involves the effort to optimise the components of the sub-system: *Runways, Taxiways and Apron areas*.

If we refer to section 3.2.1 where the different components of the sub-section are described, one can go through the same AHP-exercise to establish the relative priorities of the various components.

## PART II – OPTIMISATION ANALYSIS

### 6.8 Optimisation: Regression Analysis of Historic Data

The actual monthly aircraft and passenger movement figures of the airport for the period January 1998 until April 2009 are available for analysis.

Following are some graphs, depicting this available data, to assist the analyst in the evaluation of the traffic.

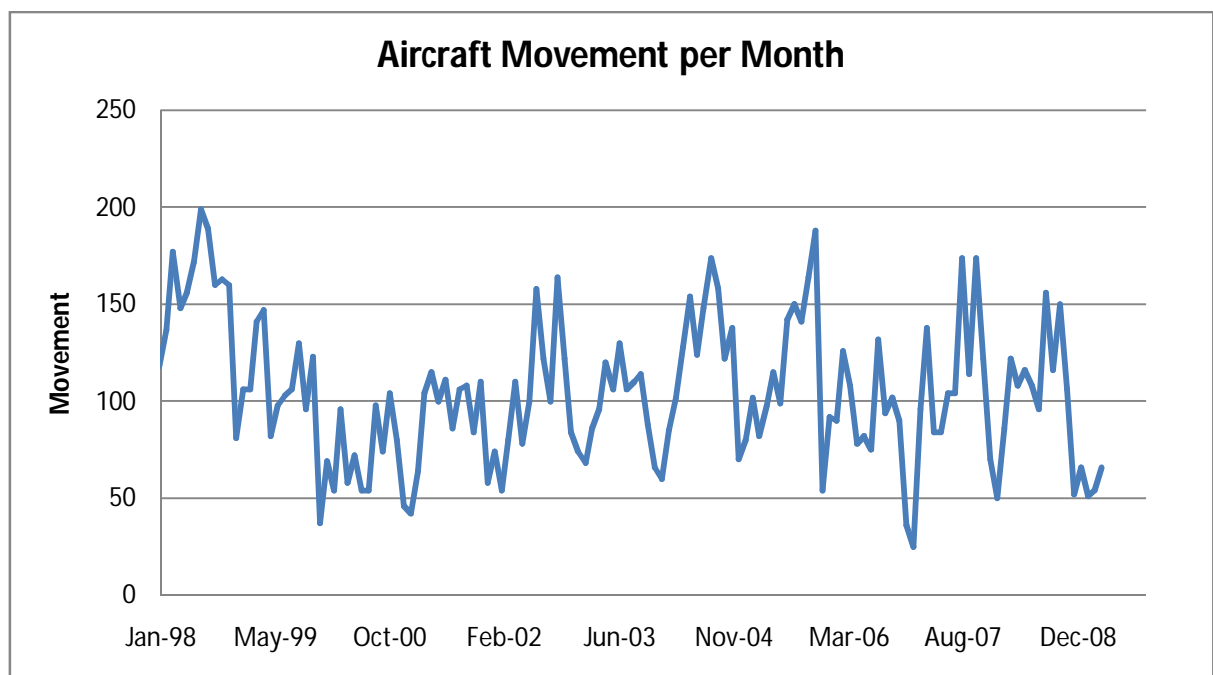


Figure 20: FYKM: Aircraft Movement per Month

Figure 20 shows a clear decline in traffic in the period before January 2000. This can be attributed to various operators, like Air Botswana scaling down, or even ceasing, their scheduled operations to Katima Mulilo significantly.

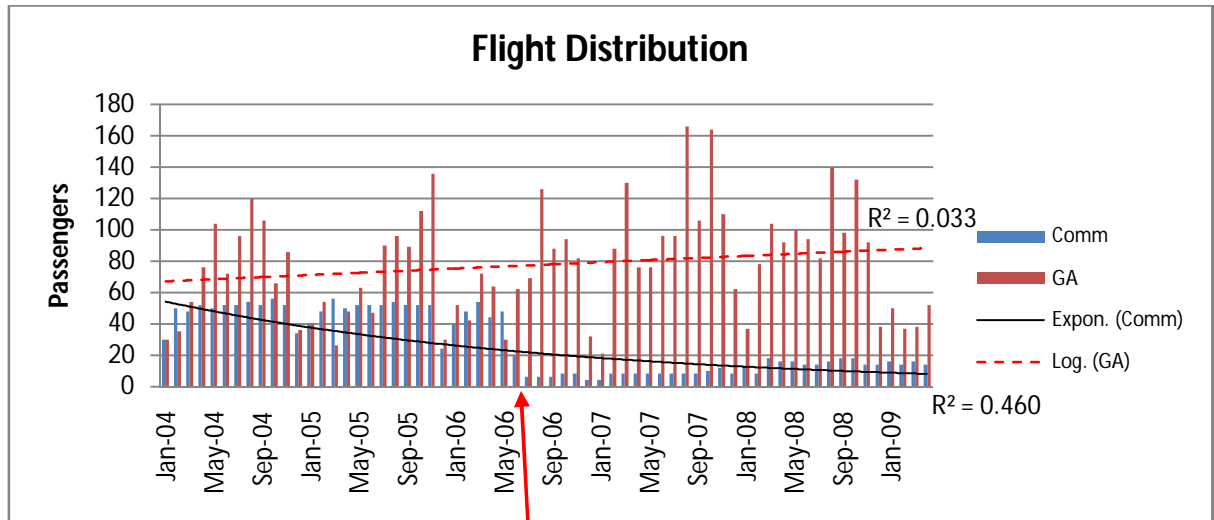


Figure 21: FYKM: Flight Type Distribution

Significant reduction of scheduled flights by Air NAMIBIA

It must be noted that *General Aviation* (GA) also includes chartered aircraft typically being used by consultants flying into the region for a short period of time or tourists chartering small aircraft. *Commercial* (Comm) flights are scheduled flights of an airline operating between two specified airports.

The only scheduled operator still flying to Katima Mulilo is Air Namibia. This airline also reduced their flights significantly in June 2006 and the effects are clearly seen in the Figure 21.

It is clear from the regression-lines that there is a small increase in the General Aviation passengers while there is a definite and continuous decline in the Commercial Flights' passengers.

## 6.9 Optimisation: Forecasting

To do proper forecasting, we must first try to obtain the best regression results.

The aeronautical operations at the airport had a definite change in purpose towards the end of 1999 when it stopped being used as a hub to the Caprivi-region and the Victoria Falls. This change in function is clearly seen in the downward trend of air traffic during the period directly prior to December 1999. To therefore determine the trend of traffic under current conditions, it will be best to only use the data from January 2000 onwards.

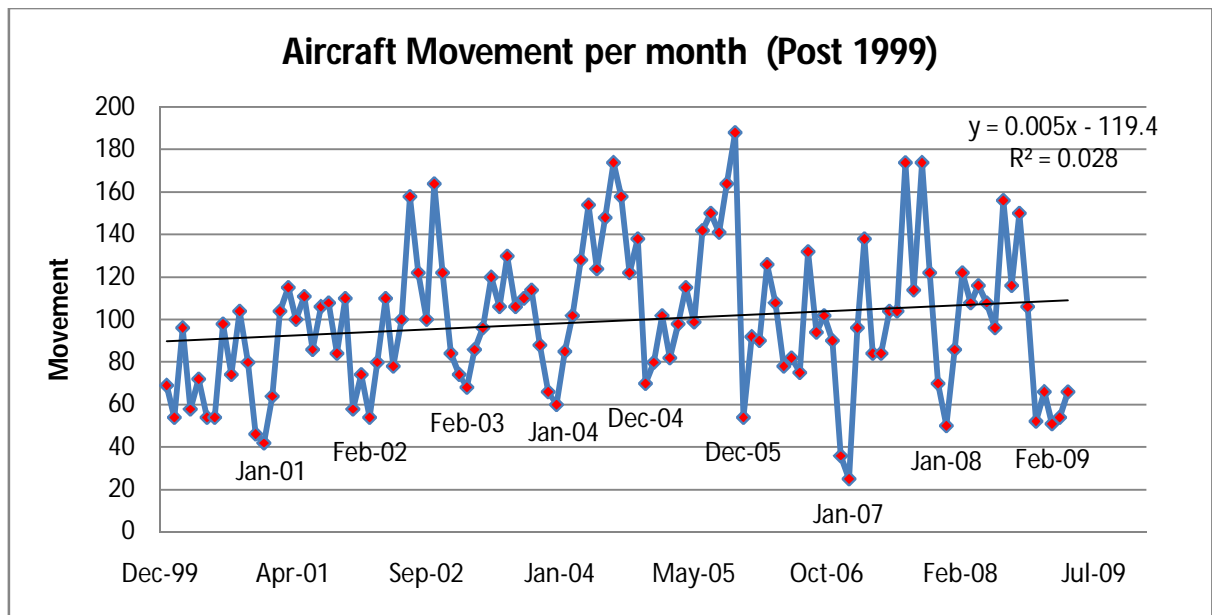


Figure 22: FYKM: Aircraft Movement per Month (Post 1999)

Since the monthly distribution gave the best indication of trends so far it makes sense to first look at the linear regression of this data. It can however be seen that the monthly distribution of traffic is incredibly volatile and this is the main reason for a very low  $R^2$  -value. The only definitive conclusion that can be made from Figure 22 is that aircraft movements generally seem to decline during the December holidays.

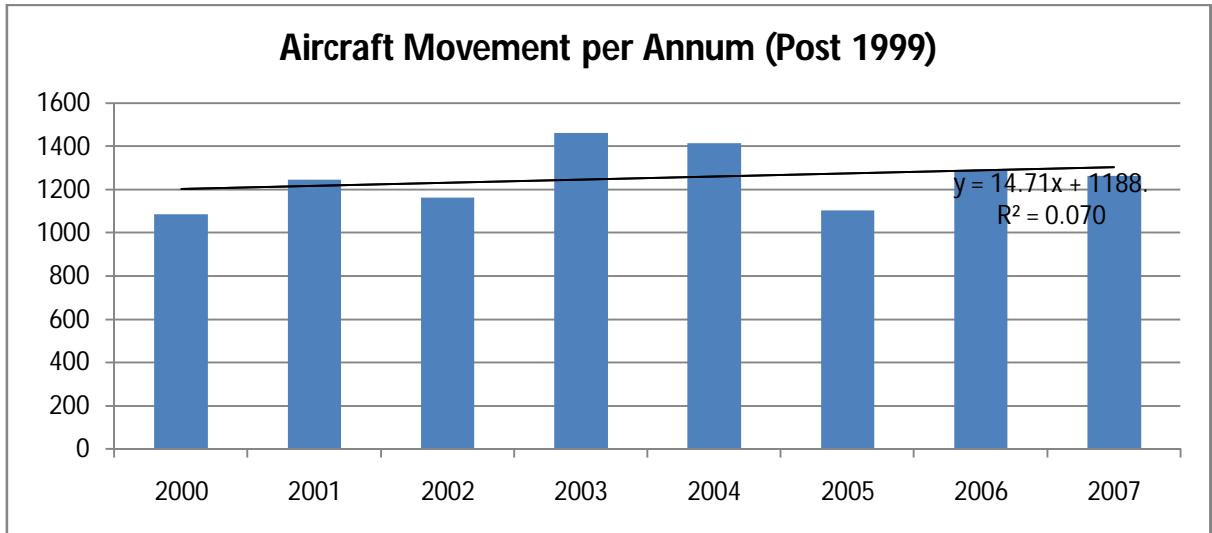


Figure 23: FYKM: Aircraft Movement per Annum (Post 1999)

By performing a regression analysis of the annual aircraft movements one can see a linear trend. Other trendlines were also tested but the linear trend gave the best fit to the graph. This trend-line gives a linear trend that can be explained by the equation  $Y = 14.71 X + 1188$ .

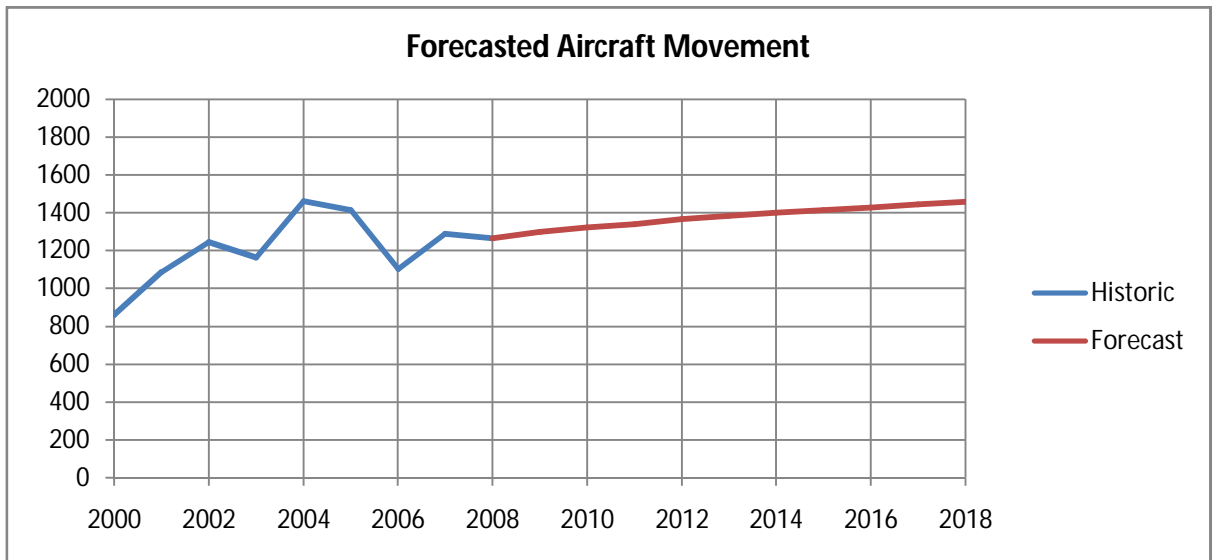


Figure 24: FYKM: Forecasted Aircraft Movement

If the historic data (Post 1999) is then extrapolated with the linear trendline derived from Figure 23, we obtain the graph presented in Figure 24. This shows clearly that, if the current trend continues, the traffic at Katima Mulilo will only surpass the previous highest traffic count, measured in 2003, in 2018 or in a 10-year horizon.

## **6.10 Runway Optimisation**

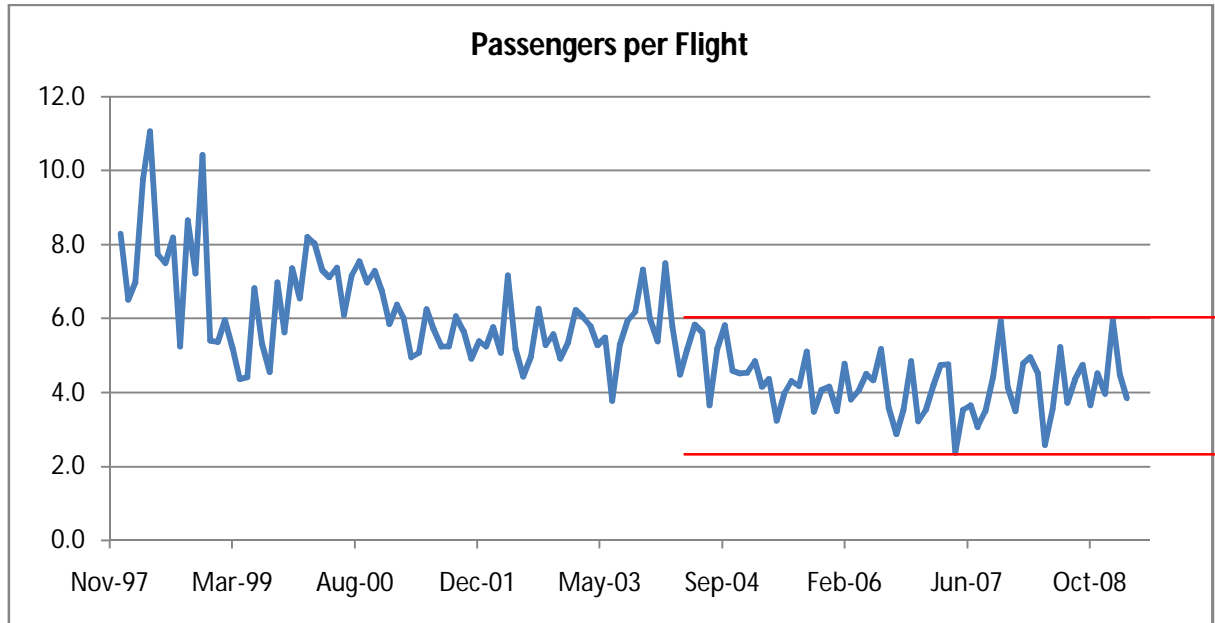
Armed with the knowledge that the traffic for the next 10 years will most probably not exceed the highest traffic count measured during the past 8 years, one can start to investigate the optimisation of the runway. The optimisation of the runway is dependent on the type of aircraft which utilises it as well as the frequency of utilisation. The next step will therefore be to try and predict the type of aircraft that will mostly frequent the airport.

### Assumption

*Please note that we do not have the Pavement Classification Number (PCN) (viz. the loading capacity of the pavement of the runway) available for this runway. By ignoring the PCN it theoretically means that any size aircraft can be accommodated on the runway, which in reality is not the case. As will be seen later on in this case study, this assumption does however not influence the study and can the PCN indeed be ignored.*

### **Aircraft Types**

If one looks at the distribution of passengers per flight for the past 11 years, as depicted in Figure 25, one can see that this also shows a steady decrease until 2004, after which it steadily fluctuated between 2 and 6 passengers per flight. This is typical to air traffic dominated by General Aviation.



**Figure 25: FYKM: Passengers per Flight**

It is therefore safe to conclude that the Average Aircraft-type that will use the airport, from a General Aviation point of view, will be those with a maximum of 7 or 8 seats e.g. Cessna 207, Cessna 402, Piper PA31 and PA42. Typically the aircraft frequenting this airport are of the Cessna 210 and Piper Cherokee Six types.

The commercial aircraft currently used by Air Namibia to service this route are the 19-seater Beechcraft 1900D or the 14-seater Cessna 406 Caravan, albeit that these flights are almost never fully booked.



**Figure 26: Beechcraft 1900D (L) and Cessna 406 (R)**

## Runway Size

Of the aircraft mentioned, the Beechcraft 1900 is the largest (Maximum Take-off Weight: 7 688 kg) and is it being used as the design aircraft. The Beechcraft 1900 requires a take-off runway length of 1100m at sea-level. To allow for the reduction in lift due to the lower air-pressure related to the height above sea-level, the runway length required at Katima Mulilo needs to be increased to approximately 1350m.<sup>18</sup>

The Beechcraft 1900D has a wingspan of 17,65m, resulting in, according to the ICAO Aerodrome Reference Code, the runway having to conform to Category 3B-runway specifications. Table 3 shows an extract from ICAO's International Standards and Recommended Practices Annex 14 – Aerodromes<sup>19</sup>, relevant to this classification.

**Table 3: Aerodrome Category as per Annex 14<sup>19</sup>**

Annex 14 — Aerodromes

Volume I

Table 1-1. Aerodrome reference code  
(see 1.3.2 to 1.3.4)

Code number (1)	Code element 1		Code element 2	
	Aeroplane reference field length (2)	Code letter (3)	Wing span (4)	Outer main gear wheel span <sup>a</sup> (5)
1	Less than 800 m	A	Up to but not including 15 m	Up to but not including 4.5 m
2	800 m up to but not including 1 200 m	B	15 m up to but not including 24 m	4.5 m up to but not including 6 m
3	1 200 m up to but not including 1 800 m	C	24 m up to but not including 36 m	6 m up to but not including 9 m
4	1 800 m and over	D	36 m up to but not including 52 m	9 m up to but not including 14 m
		E	52 m up to but not including 65 m	9 m up to but not including 14 m

a. Distance between the outside edges of the main gear wheels.

The final calculated runway size for the Katima Mulilo Airport to accommodate all traffic for the next 10 years is **1350m x 24m** wide.



## 6.11 Validity of Assuming a Linear Regression Model

In the above exercise the aircraft movement data is analysed and a regression is performed to enable forecasting of possible growth. All further decisions taken are then based on this regression-model. It is therefore of paramount importance to ensure that the data conforms to the three assumptions that support the concept of *linear regression*.

These three assumptions are:

- 1) The sample is selected at random from a population of interest.
- 2) The dependent variable is continuous on the real line.
- 3) The error terms follow identical and independent normal distributions, i.e. that the error term does not statistically depend on the values of the independent variables.

Based on the actual data for the airport these three assumptions are tested as follows:

- 1) The sample is selected at random from a population of interest.

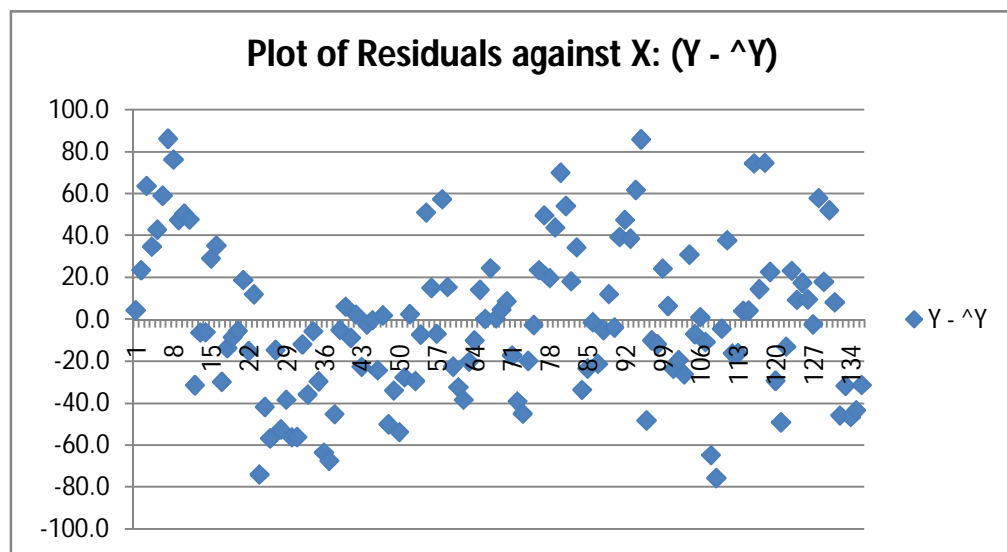


Figure 27: Scatter-graph Plot of Residuals

By plotting the residuals (Measured Y minus Forecasted Y) against X on a scatter-graph, one can look for some trend in the plots. If no trend can be derived, it is an indication that the samples are truly random and there is no underlying connection between X and Y.

- 2) The dependent variable is continuous on the real line.

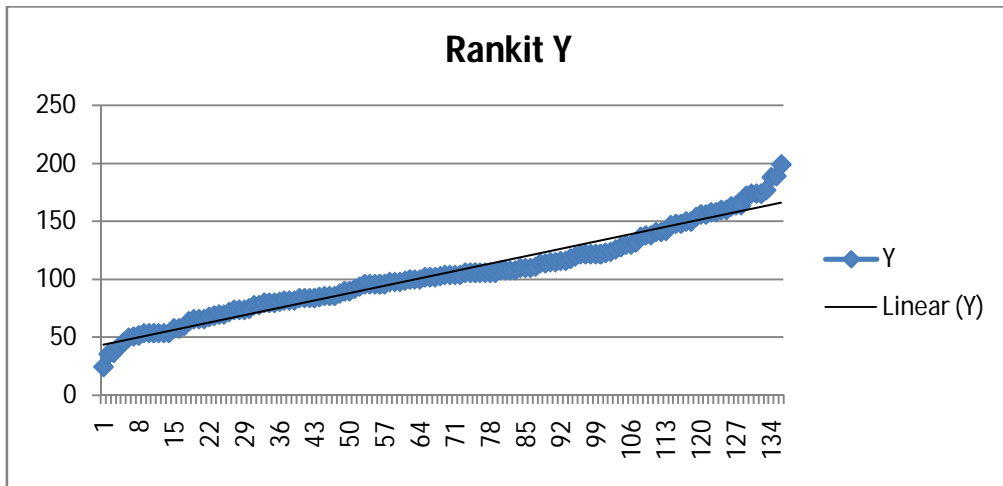


Figure 28: Rankit Plot of Dependent Variable

The *Rankit* plot of the Y-values shows an almost straight line. This is an indication that the data has a normal distribution and standard regression can be applied.

- 3) The error terms follow identical and independent normal distributions, i.e. the error term does not statistically depend on the values of the independent variables.

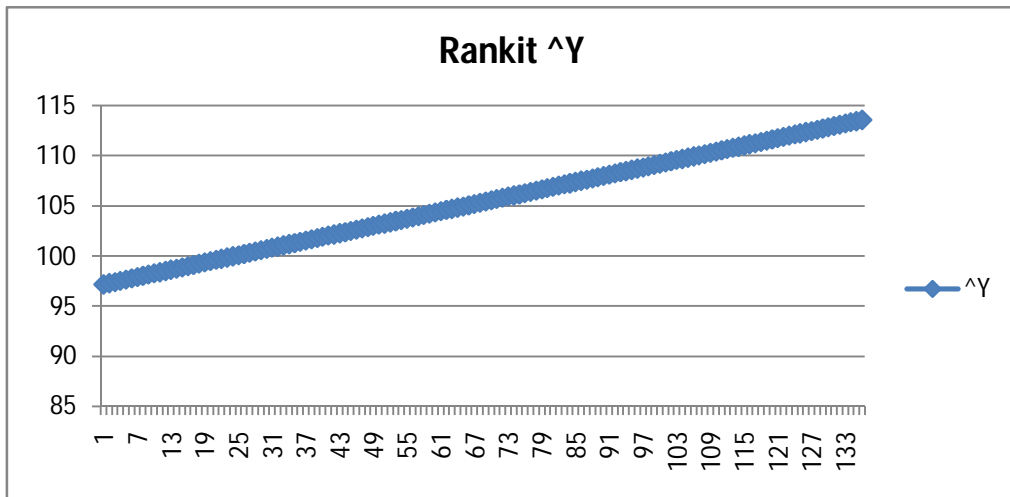


Figure 29: Rankit plot of Predicted Dependent Variables

A straight line on the *Rankit* plot of the forecasted values ( $\hat{Y}$ ) is an indication that this assumption holds true.

From the above it can be seen that it is safe to use a linear regression model to forecast the future growth potential for this airport.

## **6.12 Traffic Load Anomaly**

On normal roads and highways there is a positive and direct relationship between the traffic carried and the subsequent deterioration of the road-conditions due to fatigue. The actual major components forming part of this relationship are axle-loads, repetitions and the roads' fatigue-life. The fatigue-life is again a product of the physical attributes of that road's physical structure and material. A lot of research has been done on this subject and the root of the matter indicates that, the higher the load and/or the higher the repetitions, the more fatigue is experienced by the road. This eventually culminates in visible symptoms such as deformation of the layerwork.

Runways and taxiways of airports however, tend to move to the other end of the scale. In the case of Katima Mulilo, the 1266 movements per annum calculate to an average of 3.5 movements per day. The movements are furthermore limited to the centre or "keel"-area of the runway.

Due to the low frequency of traffic at, and the high UV-attack of direct sunlight on the airport runway pavement material, the bitumen in the asphalt-runway tends to dry out and become brittle. The brittle asphalt then tends to form cracks (so-called "Top-down cracking") formed as a result of temperature fluctuations and high UV-exposure, which again allow water to penetrate into the supporting layerwork under the asphalt. The increase in sub-asphalt moisture levels and associated pumping action all lead to a gradual reduction in the strength of the supporting layerwork which will later deteriorate to the point of structural failure of the pavement structure as a whole, resulting in potholes and a subsequent increase in the rate of deterioration.

Preventative, scheduled maintenance is required to stop this cycle before its onset and would normally include the rejuvenation of the bitumen in the asphalt-layer, as well as crack-sealing where small cracks have already developed.

Historic data indicated that this cycle of rejuvenation and crack-sealing of the pavement needs to be repeated every three to four years depending on the rate of drying. This is substantiated by a study done by Imbarek & Ali<sup>20</sup> where it was found that 62% of volatiles in bitumen are lost in the first year. The loss of volatiles increases to approximately 98% over the next three years. It is these volatiles that are responsible to keep the bitumen pliable and result in the closing of small cracks under traffic loads. The loss of viscosity due to the decrease in volatiles, along with the lack of traffic, subsequently leads to the rapid development of top-down cracking.

It is therefore evident that, for areas with low traffic numbers is it actually *beneficial* to have, with realistic terms, more traffic (repetitions) and heavier axle-loads in order

to “knead” the bituminous layerwork thereby closing small cracks that formed due to the high temperature fluctuations and exposure to UV.

The traffic anomaly therefore lies in the fact that, for small airports, higher traffic numbers and axle-loads decreases the maintenance liability. The exact stage where the amount of traffic and magnitude of axle-loads transforms from being beneficial to being a deterioration mechanism is not clearly identifiable. Continuous close inspection of the condition of the runway is the only way that one will be able to get an indication of the effects of the current loading on the condition of the runway. Current inspections indicate that the runway and taxiways are in a dire need of more traffic.

Assumption:

*To minimise deterioration, the maintenance cycle is accepted to be every three years in the case of Katima Mulilo Airport.*

### **6.13 Optimisation: Economic Analysis**

In order to allow the reader to conceptualise the effect of the optimisation effort, an illustrative economic analysis is done.

#### **Current Maintenance Costs**

If one focuses only on scheduled maintenance, one can make a provisional estimate of the expected saving in costs as a direct result of the optimisation done.

The current runway surface is 2292m long x 30m wide equating to 68 760 m<sup>2</sup>.

- Rejuvenation currently costs approximately N\$ 14 per m<sup>2</sup>, calculating to N\$ 962 640.00.
- If the amount of cracks to be sealed is assumed to be approximately 0,5m per m<sup>2</sup> it means that 34 380m of cracks need to be sealed. The associated current cost is N\$ 6/m calculating to N\$ 206 280.00.
- Total estimated maintenance cost, at current cost, is therefore N\$ 1 168 920.00.

## Optimised Maintenance Costs

Using the same criteria for the optimised runway, we can calculate the estimated maintenance cost for the optimised runway (1350m x 24m = 32400m<sup>2</sup>) to be:

- Rejuvenation currently costs approximately N\$ 14 per m<sup>2</sup>, calculating to N\$ 453 600.00
- If the amount of cracks to be sealed is assumed to be approximately 0,5m per m<sup>2</sup> it means that 16 200m of cracks need to be sealed. The associated costs are N\$ 6/m calculating to N\$ 97 200.00.
- The total estimated maintenance cost, at current cost, is therefore N\$ 550 800.00.
- This result is a saving of N\$ 618 120 per maintenance cycle of three years.

## Rehabilitation Costs

One must remember that, despite normal rejuvenation and maintenance efforts, it may still be necessary to implement a rehabilitation-project of the runway and taxiways at the end of the infrastructure's lifespan. Rehabilitation-efforts costs approximately N\$ 600 per m<sup>2</sup>.

The existing runway-size will cost approximately N\$ 41 256 000 to rehabilitate whilst the optimised runway will be approximately N\$ 19 440 000 in today's costs. If these rehabilitation costs are to be accumulated or "saved up" over a period of ten years, the annual premium is calculated as N\$ 2 588 624.01 (for the existing runway) and N\$ 1 219 770.48 (for the optimised runway) respectively.

## Maximum Theoretical Potential

The maximum theoretical potential income for a year is calculated as the number of landings multiplied with the landings fees for the *design-aircraft* plus the number of passengers times the passenger taxes.

The following figures (Figure 30) shows the landing fee-charge. It also shows the fee chargeable for the design-aircraft (Beechcraft 1900D) in relation to fees chargeable for a Boeing 737-400. The Boeing 737-400 is a medium-body aircraft regularly used for regional flights and gives a good indication of typical fees earned at larger airports.

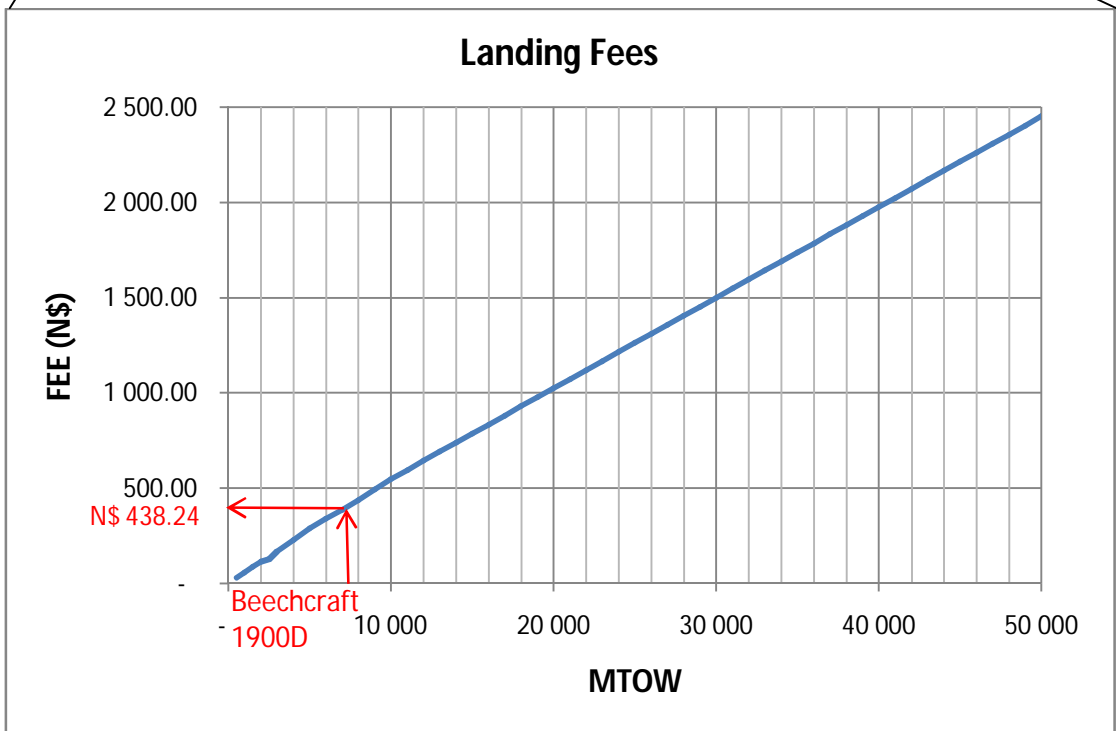
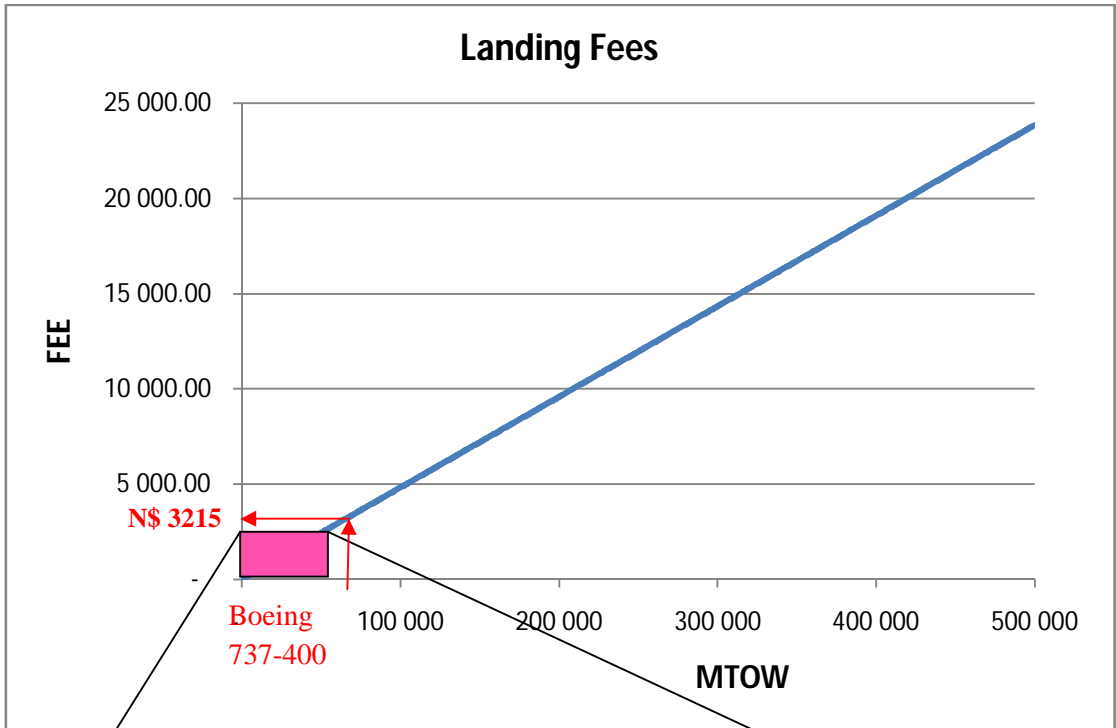


Figure 30: Landing Fees

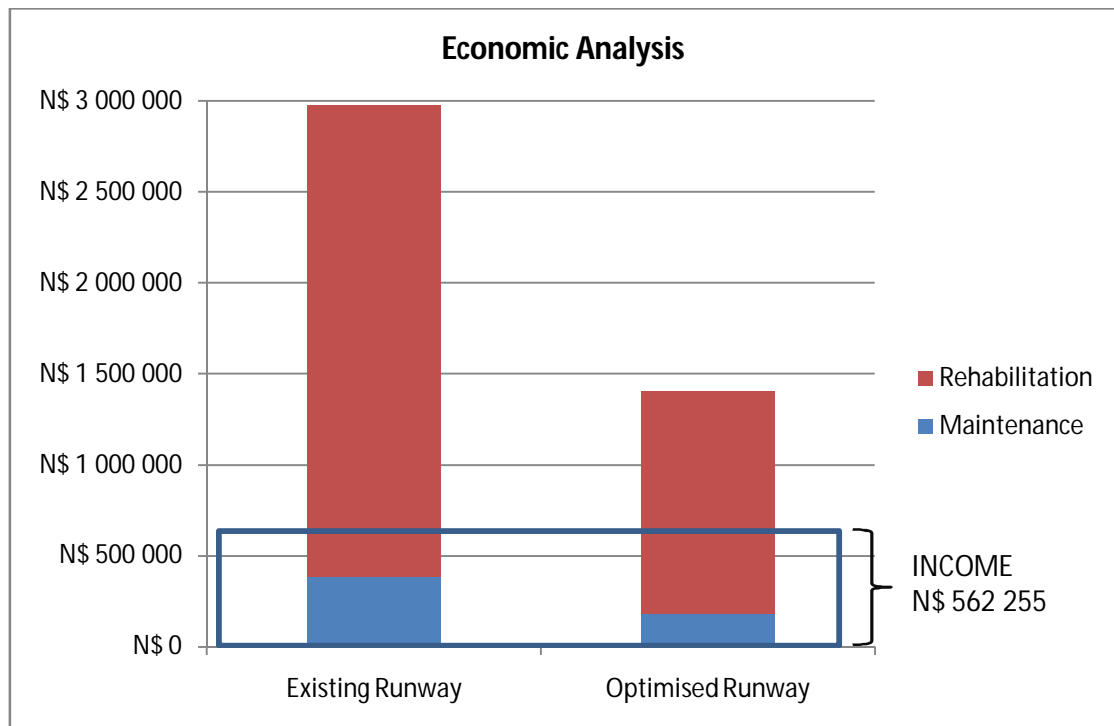
The Maximum Theoretical Potential can be calculated as follow:

Design Aircraft:	Beechcraft 1900D
MTOW:	7688kg
Number of Movements (2008):	1266 per annum
Number of Landings:	633 per annum
Landing Fees:	N\$ 438.24
Number of Passengers:	1266 x 6 = 7596 per annum
Passenger Taxes:	N\$ 75 per person
Total Fees (2008):	$633 \times \text{N\$ } 438.24 + 7596 \times \text{N\$ } 75$ $= \text{N\$ } 277\,405.92 + \text{N\$ } 284\,850.00$ $= \text{N\$ } 562\,255.92 \text{ per annum}$

The theoretical potential increases to N\$ 647 526.96 in 2018 as a result of the forecasted increase of traffic to 1458 per annum.

It is important to note at this stage that, due to the size of the airport with the associated lack of traffic and passengers, the income collected from passengers taxes and landing fees may constitute the greatest part of, if not the only, income for the airport. This income therefore not only needs to cover the calculated maintenance expenditure but also the operational expenses associated with the day-to-day running of the airport.

## Economic Summary



**Figure 31: Rehabilitation & Maintenance Needs vs. Income**

Figure 31 shows the financial needs for both the existing- and optimised runway for the airport in respect of maintenance and rehabilitation financial requirements relative to each other.

It also indicates, in the blocked area, the current financial income from that runway. As indicated earlier, one must remember that this income encompasses most, if not all, the income at the airport.

The following ratios can be derived from Figure 31:

	Existing Runway	Optimised Runway
Proportion of Maintenance Requirements to Income	69%	33%
Proportion of Income to Maintenance & Rehabilitation Needs	19%	40%



## **6.14 Optimisation: Sensitivity Analysis**

The optimisation process used for this specific component is relatively straightforward with the only assumption being the future growth of 1.5% per annum. It is important that the effect of both higher- and lower-growth must be considered by the Airport Authority before any drastic changes are made. The growth trend should also be re-measured on an annual basis to test the original assumptions made and to make strategic adjustments if necessary.

Furthermore, are the landing fees for an aircraft derived from that aircraft's Maximum Take-off Weight (MTOW) and the fees increases at a rate of N\$ 47.59 per 1000 kg. Changing to a design-aircraft with a higher MTOW will therefore have limited effect on the Maximum Theoretical Potential.

## **6.15 Conclusion for Case Study**

The calculations gives one a quantified indication of the potential savings one might gain from going through an optimisation exercise for infrastructure. In this case, by reducing the runway length with 42% an approximate saving of 53% per maintenance-cycle is achieved.

It is clear that the runway-length and -width is directly related to the Type and Classification of aircraft that will make use of the airport i.e. the design-aircraft. The determination of the design aircraft must not only be done from a practical point of view, but also from a strategic perspective. Strategic importance includes both the importance to the owner and the possible national and regional influence or significance such an airport may have.

The low number of flights and passengers of a small airport suppresses the effect of aircraft sizes, weights and frequencies on the economic analysis. Attention should therefore be directed to the infrastructural optimisation process rather than traffic-related optimisation.

Where an airport authority is required, due to regional- or national socio-political strategies, to maintain the existing infrastructure, a quantified- and qualified bid for financial support can be presented to the regional or national authorities, based on the concept envisaged in this study.

It is evident that it is of the utmost importance to any airport authority to continuously investigate, from a strategic as well as operational perspective, the complete system requirements at its airport/s. Failure to have a plan of action will result in an unnecessary waste of valuable resources.

## Chapter 7 – Conclusions and Recommendations

The concept of the systematic unravelling of a problem to known, recognisable parts and the subsequent analysis of those parts to derive at a relevant and useful answer stand central to the engineering fraternity's *modus operandi*.

It however becomes increasingly more difficult once human-interaction forms part of the problem as attributes like perception and feelings cannot be transferred into a mathematical model. It is therefore sometimes necessary to utilise a tool that, to some extent, allow the analyst to incorporate these and other types of fuzzy attributes in the analysis of the problem.

### 1.1 Conclusions

This document was created around the need to develop a strategy to find more optimum solutions to superfluous infrastructure at small airports. It shows how, through systematic analysis, one can come up with a set of answers that can be implemented and will have a positive feedback to the airport's management.

The concept of the strategy will be the same for any variations in relation to the industry and the value of this strategy therefore reaches to more than only airport operations but can be used in facility management as a whole irrespective of the industry.

The AHP as a multi-criteria decision making tool is flexible enough to allow for some degree of inconsistency normally associated with human-interaction. This is necessary as human-interaction is required during the pairwise-comparison stage. It is also this human-interaction that empowers this method's results to be "sold" to decision-makers as being more than computer-generated mathematical solutions which have little or no connection with reality. Even more if the decision-makers were also responsible for the pair-wise comparisons in the first place.

The further incorporation of sensitivity analysis both on the AHP and optimisation process allow the user to understand the exact scope and boundaries of the end-results.

### 1.2 Recommendations

1. It is important that the user at all times knows that the results of both the AHP and the optimisation were derived from field-data. Just as the field-data will vary over time, is it possible that the requirements or attributes used also may

vary over time. The user or analyst must therefore be prepared to understand and appreciate the subsequent changes this will have on the model developed.

2. The value of this strategy will be greatly enhanced if, during the initial-phase, real effort is made in clearly identifying the three input-levels to the AHP namely the goal, attributes and components. Once this has been done, this model can be re-used time after time to ensure that the firm's infrastructural management stays optimised.

This embraces the Japanese-developed strategy of *Kaizen* or *Continuous Improvement* towards a leaner system.

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# Appendix

## PAIRWISE COMPARISONS BETWEEN SUB-SYSTEMS AT THE KATIMA MULILO AIRPORT

Please show the relative importance of one sub-system relative to the other in specific relation to the evaluation criterion highlighted.

*For instance:*

With regard to the Safety Impact:

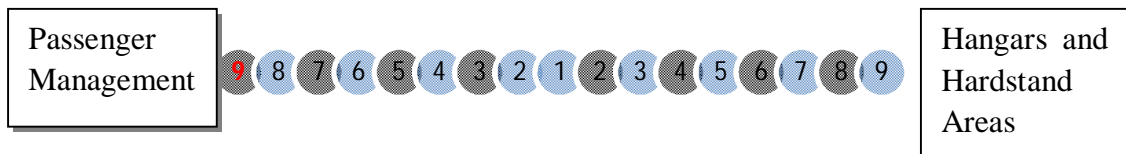
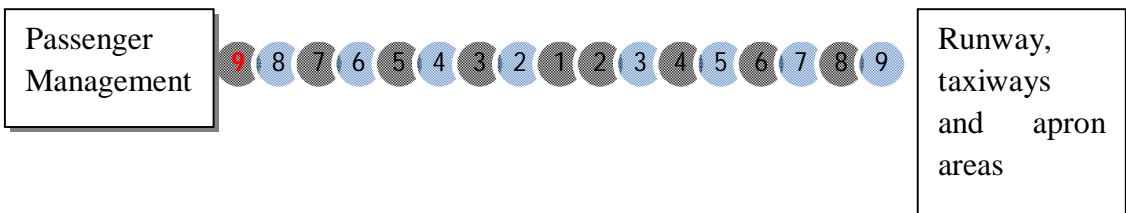
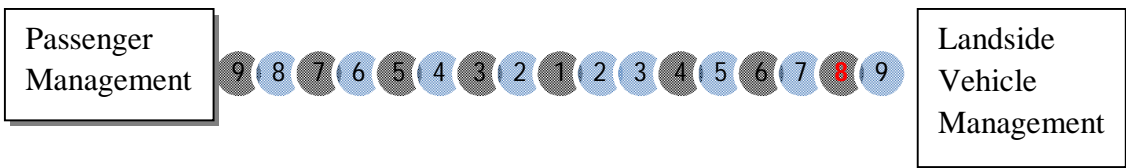
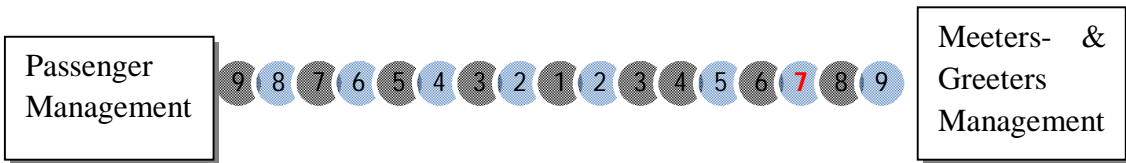
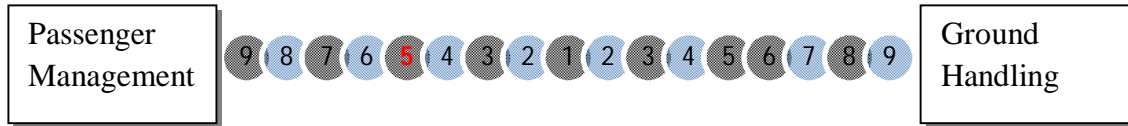
If the Passenger Management is considered to have a higher Safety Impact than the Ground Handling, the item with the **lower** impact (e.g. Ground Handling) is to be penalised. The size of the penalty should be given in accordance with the table below.

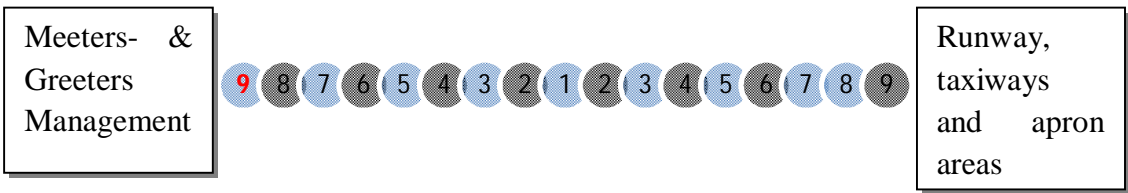
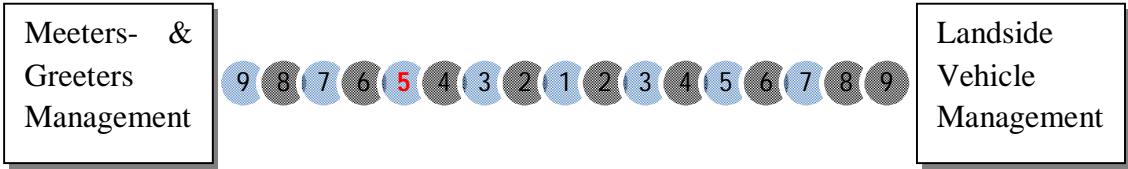
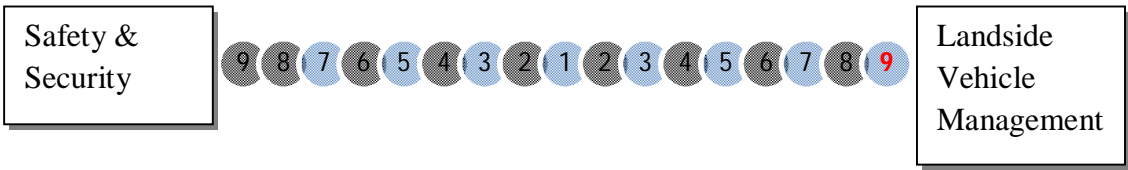
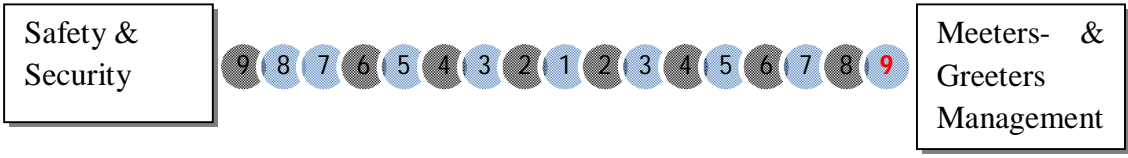
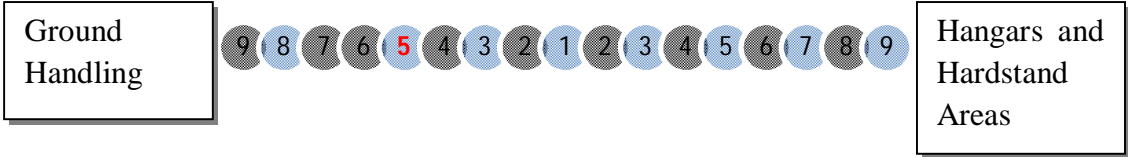
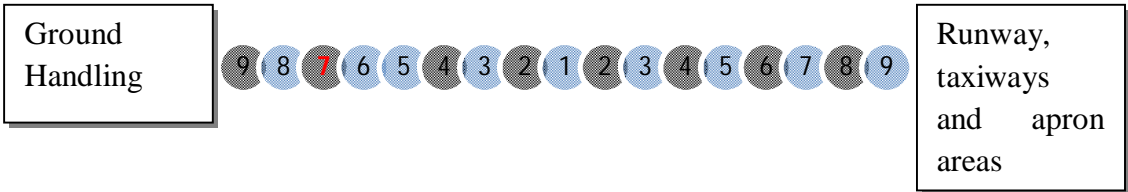
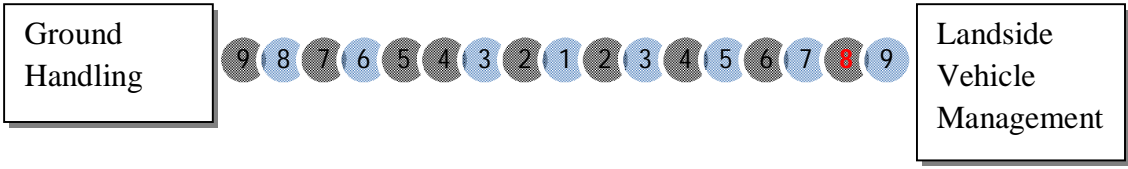
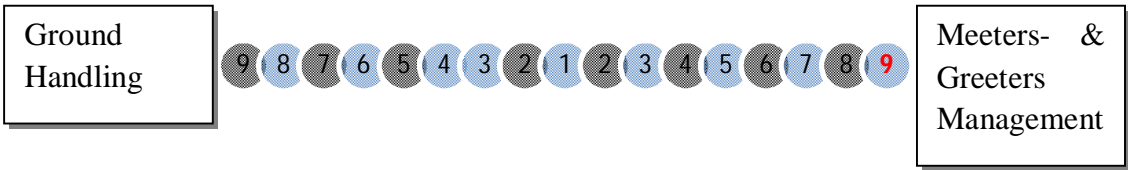
Where two items have the same impact, a score of 1 should be given.

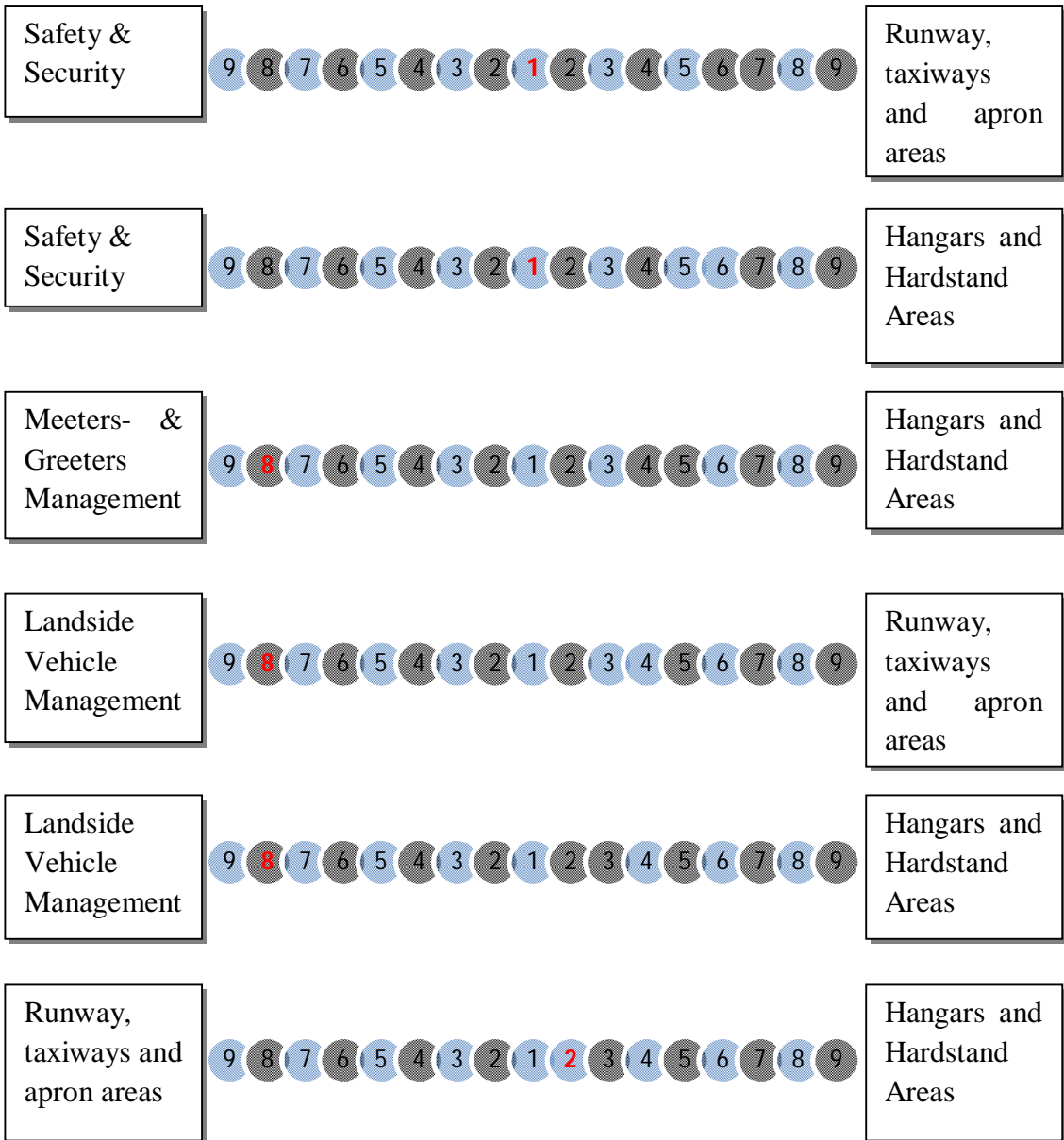
<b>Intensity of Importance</b>	<b>Definition</b>	<b>Explanation</b>
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and Judgement slightly favour one activity over the other
5	Essential or Strong Importance	Experience and Judgement strongly favour one activity over the other
7	Demonstrated Importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute Importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed



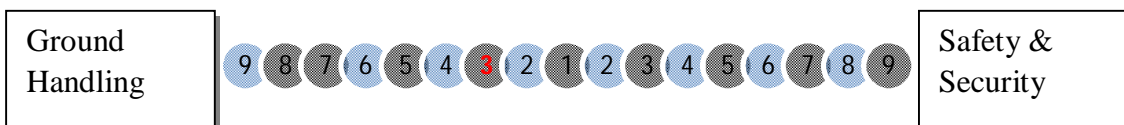
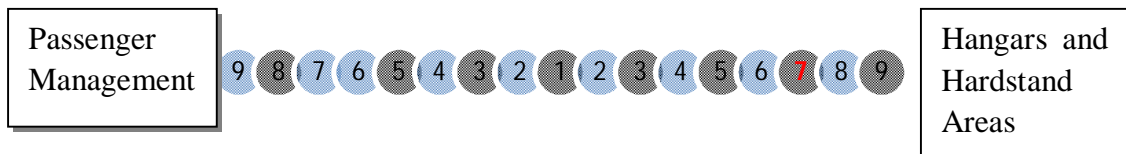
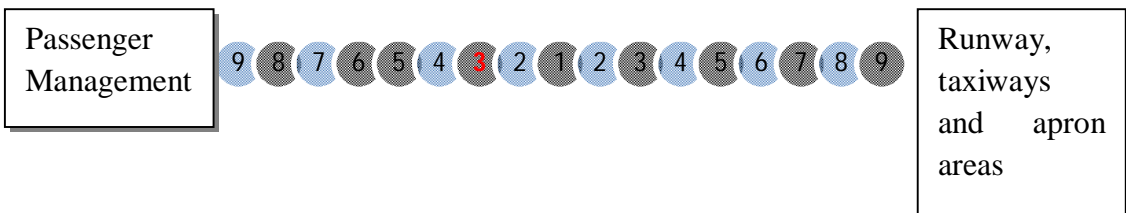
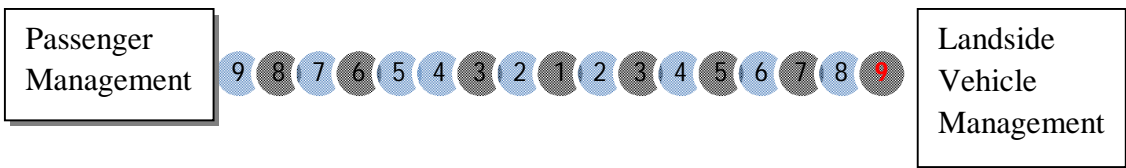
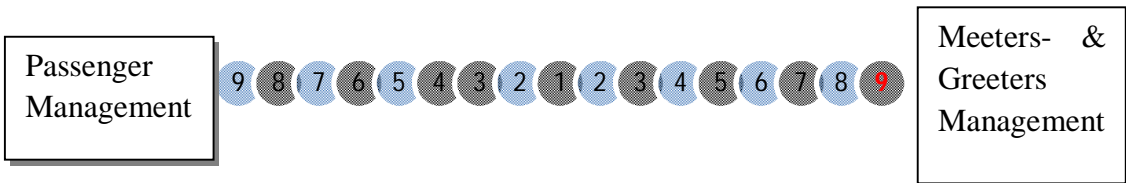
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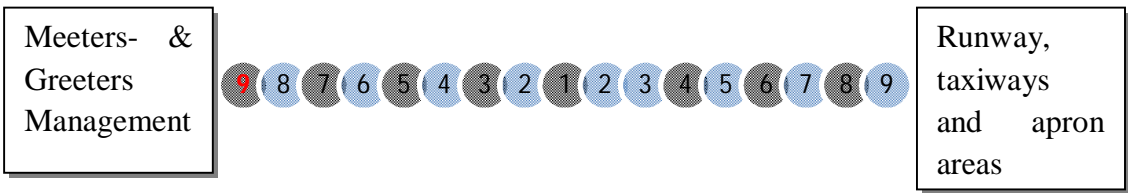
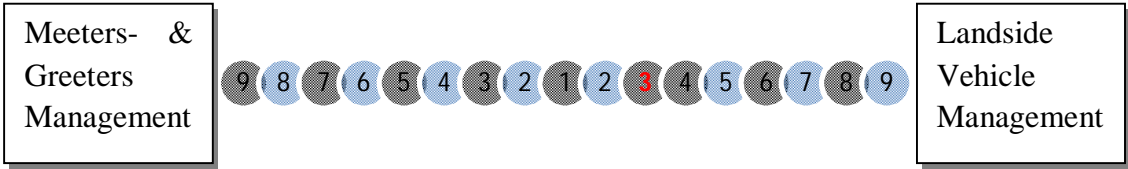
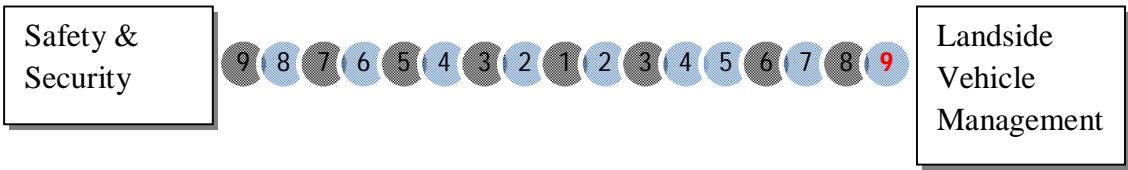
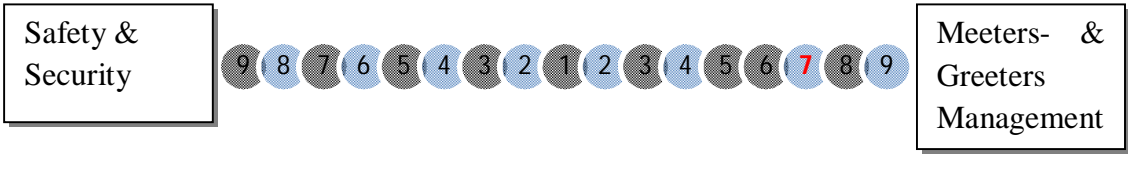
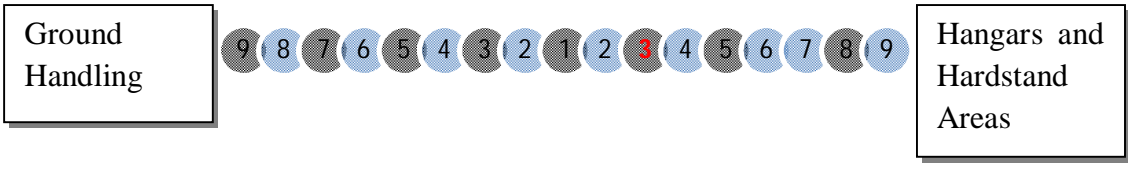
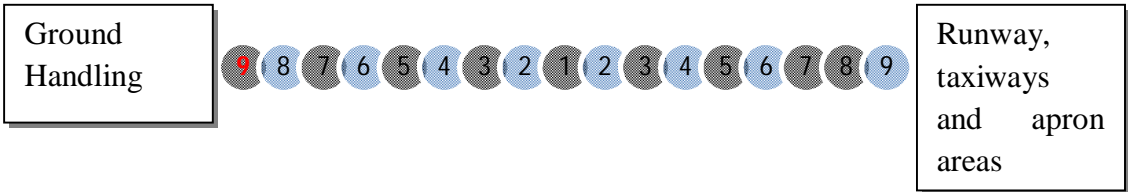
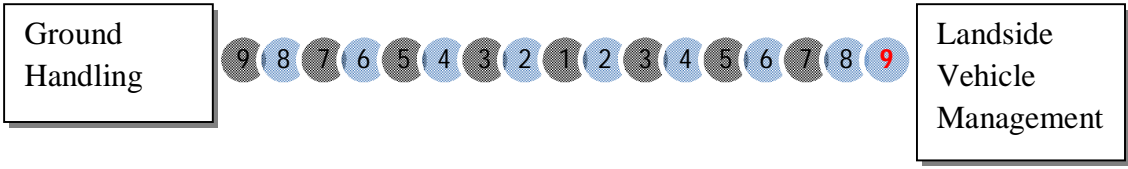
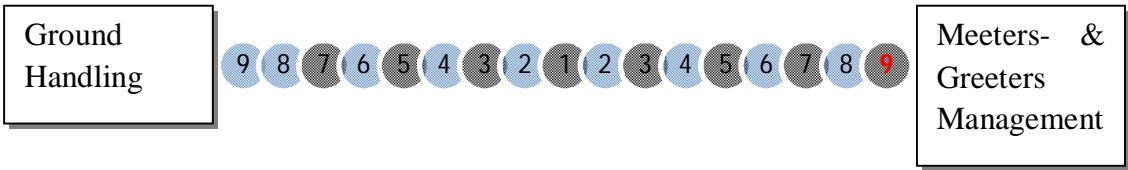


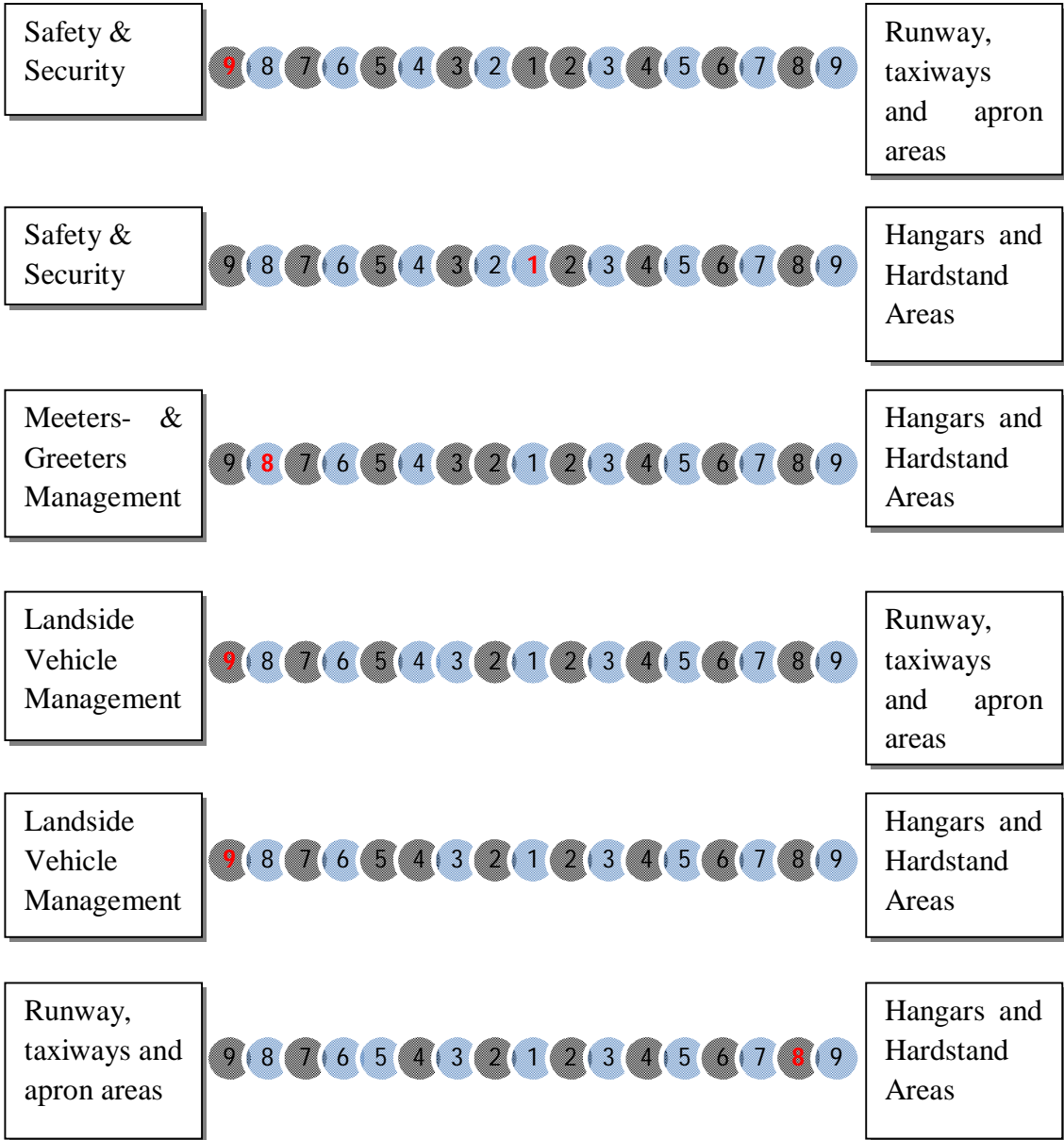




# REVENUE POTENTIAL







# MAINTENANCE REQUIREMENTS

