IMPROVING BAGGAGE HANDLING SYSTEM INFRASTRUCTURE AT BANDARANAIKE INTERNATIONAL AIRPORT

By

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The Dissertation submitted to the Department of Civil Engineering of the University of Moratuwa in partial fulfillment of the requirement for the Degree of Master of Business Administration.

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Declaration

"I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any University to the best of my knowledge and belief, it does not contain any material previously published, written or orally communicated by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and for interlibrary loans, and for the title and summary to be made available to outside organizations"

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Supervisor Date

(Prof. J.M.S.J.Bandara)

Abstract

The Report is the outcome of a Research carried out on the Improving Baggage Handling System (BHS) Infrastructure at Bandaranaike International Airport (BIA) in Sri Lanka. The main objective of the study was to find ways and to make recommendations to improve the efficiency and effectiveness of the Baggage Handling System. The Data used in the analysis were the capacity of available baggage belts, passenger capacity and the corresponding baggage capacity of different types of aircrafts operating to BIA at present and types, which may operate in future. The Resource Allocation Model called 'knapsack / fly-away kit model' available in Dynamic Programming under the broad subject of Operations Research was used to model the problem and to find the optimum solutions. The solutions so derived show that there can be many ways of utilizing the available Baggage Belts to accommodate different types of aircrafts so that the Total Return will be maximum.

A sensitivity Analysis has been done to study the behaviour of 'Total Return' with the change in the ratio between 'Baggage unloading rate (D)' and the 'Baggage Loading rate (a)' . The analysis revealed that that by increasing the (D/a) ratio would increase the 'Effective Capacity' of Baggage Belts. Different options available to increase the (D/a) ratio have been described in the report. The study also highlights the importance of ensuring and maintaining the Level of Service (LOS) to passengers when meeting the expected demand created by the operation of New Large Aircraft (NLA) such as Airbus – A 380. The report critically reviews the trends in Baggage Handling and various technologies available for use at present and in future. It also covers the subject of mishandled / lost baggage, which is a critical issue in Baggage Handling operation, and gives recommendations on how to minimize the issue. The outcome of the research will be equally useful in the planning and development of Baggage Handling System Infrastructure and Baggage Handling System operations, to both the Airport Operator and the Ground Handling Agent alike.

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1. Introduction

1.1 Background

Bandaranaike International Airport (BIA) is the only International Airport in Sri Lanka, which is serving International Airlines since late 1960 s. This has been upgraded initially in 1971 and subsequently in 1986 under the BIA Phase-I Development Project (BIADP – Phase I). Currently it is being further upgraded under BIADP-Phase II – Stage I Project.

The total Passenger (PAX) volume exceeded 4 million in 2004 and the number of aircraft movements in the same year exceeded 35,000, which are the highest recorded figures in the history. (Table A - 5)

The average passenger growth rate is 7.89 % and the average aircraft movement growth rate is 5.49 % (Table A – 2). It is noted that there is a steady growth in the number of Transit / Transfer Passengers during the past few years and accounts for 14.96 %, for the year 2004, of the Total Passengers while having an average growth rate of 81.8 % per annum (Table A - 4)

With the increase in aircraft movement and the subsequent increase in passenger and cargo handled by the airport, all infrastructure and systems, services and facilities to be expanded or upgraded to cater for the present demand and the demand in years to come.

Baggage Handling is one of the most important and critical operations for both Airlines and Airports / Ground Handlers.

It is no doubt that the Baggage Handling System (BHS) Infrastructure at any international airport must be able to cope with the increasing demand and expectations of all stakeholders and the BIA is not an exception.

However, due to the rapid growth in Sri Lankans travelling overseas, the increase in tourist arrivals and the continuous growth in the number of Transit /Transfer Passengers some of the Airlines operating to/from Colombo have ambitious plans to operate New Large Aircrafts (NLA) such as Airbus A380 by the year 2008, to transport passengers to / from Sri Lanka.

Therefore, the growing passenger numbers, tight aircraft turnaround times, changes in the industry such as the introduction of NLA s, tough new security regulations in today's high-pressure operating environment, keeping track of the large Number of baggage to be handled at BIA have become a major challenge.

In meeting the demand for above, especially with the increase in demand for shorter aircraft turnaround times, the BHS infrastructure should be upgraded or expanded to ensure efficient and effective Airport Ground Handling Operations and to make the airlines operating to Colombo to be competitive and efficient in delivering their service.

The basic principle in the design and operation of BHS infrastructure is to facilitate the movement of baggage with the passenger in a coherent manner. At the beginning of the journey the passengers and their bags depart but towards the end of the journey they must re-unite at the correct place and at the correct time. The passenger movement is unique and associated with the processes in an Airport. Therefore, due attention should be given to such processes in achieving the desired objectives.

1.2 Baggage Handling Process

Baggage Handling Process at any airport in general, is one of the most important processes, which is quite complicated as passengers and their baggage depart at the time of check-in but must be re-united at the end of the journey without any inconvenience to the passengers.

Usually in many airports, passengers are to check-in while their baggage is handed over to the custody of Airline. At that point the officer at the check-in counter might ask few questions and issue one or more baggage tags depending on the number of baggage. While doing that a sticker, indicating baggage details, is affixed on to the Airline ticket for reference purposes while issuing a Boarding Pass as well.

From here onwards, the baggage departs from the passenger and starts its journey to the destination, while remaining in the custody of the airline.

In the process, the baggage first goes to Baggage carousel in the Baggage make-up area where the baggage handling staff (Baggage loaders) is waiting for the baggage to be scanned and loaded to the respective Unit Load Device (ULD). Each ULD is assigned a number and by scanning the number before starting loading, will make the ULD register in the Baggage Reconciliation System (BRS) system. Then the baggage are scanned and loaded to the ULDs (containers) registered for despatching to the respective aircraft. These ULDs are mounted on Dollies and transported in groups to the aircraft / apron where they are loaded to the aircraft using high-loaders.

These ULDs are used in wide-bodied aircrafts such as B 747, A 330, A 340 only and in the case of narrow bodied aircrafts baggage are handled piece by piece and transported in Baggage Trolleys.
The Reconciliation of Baggage with the passengers boarded takes place during this period and if any passenger has not boarded the aircraft, his/her baggage is unloaded from the aircraft. This process of locating and unloading the baggage has become easier and faster due to the details given by the BRS System on the Liquid Crystal Display (LCD) of the Hand Held Scanner and the "Load Control Sheet" available for the relevant aircraft.

On arrival of the baggage at the destination airport, they are unloaded from the aircraft and transported to the baggage unloading area and loaded on to Baggage Re-claim Belts. As the Baggage Re-claim Belt assigned to each flight is displayed on arrival of passengers to the Terminal Building, passengers can re-claim their Baggage from the respective baggage re-claim belt after completing immigration formalities.

Some of the important areas / processes / stages of the Baggage Handling System / Operation are shown by Figures B1-1 ~ B1-6 and B2-1 ~ B2-6 in Appendix – B.

1.3 Problems

With the increase in passenger volume, especially the transit / transfer passenger, the volume of transit / transfer baggage is also expected to increase steadily. This will have a significant impact on the Baggage Handling Process and other ground handling operations in the airport. Further, this may have an effect on the Aircraft turn-around times which in turn will have cascade effects on all the processes such as check-in, aircraft interior cleaning, boarding to other aircrafts, loading of cargo and baggage, re-fuelling and other requirements such as catering services etc. to other aircrafts at BIA and may lead to delayed arrivals at other airports. The Airlines may incur heavy losses as a result of this. Therefore, to ensure a trouble free operation while maintaining the maximum passenger comfort and to maximise airline's profit or to minimize the loss, it will be essential to perform all processes related to baggage handling, among other airline operations, in a highly efficient and effective manner.

In doing this, it is vital to have selected the most suitable and cost effective method to meet the demands stated above.

The number of mishandled baggage is also an important parameter in the efficiency and effectiveness of baggage handling process. With the increase in amount of baggage handled, due to growth in passenger volume, it is important to maintain the ratio between the number of baggage mishandled and the total baggage uplifted.

1.4 Purpose of the study

The purpose of this study is primarily;

- To find solutions to remedy the problems and challenges mentioned above and to recommend suitable methods and processes to overcome them after a detailed study of the current Baggage Handling System at BIA.
- To compare the process with other leading airports in the world.

1.5 Objectives

1. To study the trends in Baggage Handling operation and comparison of the systems adopted by other Airports with those of BIA.

2. To improve the operational efficiency and throughput of the Baggage Handling System after studying different alternatives and recommending the most suitable and the most cost effective methods / solutions.

3. To find ways to minimize the number of mishandled / lost baggage and to recommend processes, which will minimize airline operational costs.

4. To find the impact of New Large Aircraft (NLA) - Airbus A 380 - on Baggage Handling operations at BIA and to recommend solutions to meet the expected demand.

1.6 Importance of the Study

The study is highly relevant and useful to both Airport operator, Ground Handling Agent and the Airlines equally as a similar study has not been carried out so far besides the fact that both the airlines and airport operator have to find ways of meeting different stakeholder demands in the best possible manner while maintaining the international best practices.

1.7 Research Design

The research has been entirely based on;

- the data / information made available in the data base of the Ground Handling Agent at BIA, Sri Lankan Airlines Ltd., which is also the national carrier based in Colombo having a fleet of 12 passenger aircrafts.
- Interviews with the officers responsible for various processes in the Baggage Handling and other Ground Handling operations.
- material available in the internet, research publications, relevant to the broad topic of Baggage Handling, international best practices / recommendations given in publications such as International Air Transport Association (IATA) Airport Reference Manual etc.

It has been attempted to model mathematically and find solutions to the problem: the optimum utilisation of the Baggage Belts and compare them with the peak hour aircraft arrivals in year 2015 and to analyse the two scenarios namely with and without the presence of NLA - Airbus A 380.

1.8 Nature & Form of Results

The nature and form of results would be the ' Maximum aircraft mix ' (combination of different types/categories of aircrafts) which would optimise the utilization of baggage belts, by maximizing the Return, and various Recommendations derived based on the Results obtained after the study.

1.9 Limitations of the Research

The research encompasses only the processes within the check-in, baggage make-up / sorting area in the case of departures and baggage unloading area and baggage re-claim belts / area in the case of arrivals. This research study does not cover various processes related to Baggage Security such as Hold Baggage Screening and similar issues.

2 Literature Review

2.1 Trends in Baggage Handling operation and comparison of the systems adopted by other Airports

Most of the large airports like Singapore, Bangkok, London - Heathrow, New Delhi, and Madras etc. use Bar Code Scanning in their Automated Baggage Handling Systems.
However, according to Pankajnarayan Pandit (2004), the IATA (International Air Transport Association) has endorsed a new technology far more superior than next generation barcodes called Radio Frequency Identification System (RFID) and has taken a leading role in simplifying airline baggage management with the use of RFID technology.

IATA expects that RFID will achieve the following.

I. Improve service considerably in terms of reductions in mishandled baggage and new security requirements.
II. Increase speeds in sorting and scanning systems.
III. Reduce baggage tag read errors.
IV. Lower scanner maintenance costs.
V. Allow the ability to scan bags in a baggage container that cannot be scanned by an optical scanner.

Airlines also see RFID technology that will help in tracking ULDs, premium express Cargo across their network and comply with the new security regulations. Yet all airlines are not rushing to commit funds for deploying the RFID Technology.

2.2 Technology used in Baggage Handling / Reconciliation: Bar Code Scanning Technology in brief.

Most of the International Airports at present have Bar Code Technology driven Baggage Reconciliation Systems. Besides, this technology is one of the best for tracking various functions. Basically, all the Airline Hosts around the world print information using standard bar codes in the Bag Tag and this has been used effectively to track the baggage.

Industrial scanners are used to scan the bar code in the Bag Tag and this information can be verified against the passenger status data in the Airline Host. (Containing the unique Baggage ID). This on-line baggage data can be used to match the scanning Bag Tags.

The Supervisors can register ULDs when they are released for operations and the baggage loaders can login to the scanners; register the ULD that they are working before starting the scanning of bags. The scanners should be able to communicate, preferably via RF, with the baggage system database. The scanned information is verified against the passenger data and the ULD, thus making the system capable of deciding which particular bag should go into the working ULD.

Therefore, the decision making process is basically handled by the system, prompting the loader to 'load' or 'not to load'. It is to be noted that the system can record all the decisions made; i.e. who has scanned the bags and provide instantaneous Information as and when required.

As most of the Airline Hosts print standard Bar Code Bag Tags, these can be effectively used in airside transits. Bags are off loaded on the tarmac (Apron) near the Aircraft and passengers are allowed to go to the transit desk in the process. After passengers have re-checked-in, the bags can be scanned, verifying the latest check-in information in the Host against the Bag Tag bar Code data. Thus, it would be possible to match passenger baggage on one to one basis during a transit and filter the bags, which do not belong to the boarded-in passengers. This way, by using bar code scanning technology, it is possible to eliminate the Baggage Identification Process (by passengers themselves) and cut the time and manpower required for such an operation.

Since on line information is available between Airline Host check-in desks and the Baggage Hall, it is possible to reduce the time taken for loading an Aircraft resulting in reduced Aircraft turnaround times and increase-in efficiency.

Besides, the above advantages which reduce overall operational times, it provides the ability to handle multiple flights by the same loaders, elimination of security baggage ID, quick transfers, quick off –loading, enhanced reporting capabilities etc. There are also other specific advantages and disadvantages associated with the usage of Bar code technology as given below.

(a) **Advantages of Bar Code Technology.**

1. Bar-coded Bag Tags are produced by Airports worldwide and can be readily used. No extra cost will be associated with producing Barcodes from the Baggage IDs assigned by the Airline Host.

2. Bar code scanners are not expensive equipment. As this technology is mature, there are different sizes and products in the market. It is not required to manufacture specific devices (scanner) as they are available in the industry / market.
3. Barcode scanner software and communication technology (TCP / IP) is not difficult to develop and deploy, as many industries use them at the moment.

4. Design of Barcode scanning Baggage Reconciliation System is not very complex.

5. It is flexible enough to support Baggage Hall scanning as well as airside transit scanning. In the latter case RF connected scanners are required if used in open Airport areas.

(b) **Disadvantages of Bar Code Technology.**

1. Loaders need to attend to individual bags and must scan them properly getting closer to them. Needs 'line of sight' direct aiming for scanning a barcode (even with a laser pointed scanners). Thus, it is not possible to reduce the number of loaders required for individual flights. It is not possible to scan a bag without human intervention.

2. Human errors and deliberate actions of unauthorized loading do not get notified immediately. Thus, there still can be mishandled baggage (since the loader is responsible for physically loading bags into ULDs) as well as security breaches.

3. It is not possible to do a quick reconciliation during a security breach without attending to all the baggage.

4. Scanners can get damaged often as they are handled by loaders.

5. Efficiency of the system directly depends on the loaders ability and skill to scan and load the bags.

6. Barcodes (standard ones used in the Bag Tags) contain a few information, thus it is always required to process the bar-coded information and cross check with the Database. This may cause delays in response time, which is significant in peak hour operations.

2.3 Radio Frequency Identification (RFID) Technology in brief.

RFID is a smart sensing technology, which is based on the use of Radio Frequency (RF) signals for sensing. Essentially the technology consists of two components. The first is the RFID tags that consist of a chip which holds stored digital information, an antenna which communicates with the receiver and the packaging which ensures that the combination of the chip and the antenna is rugged and in a package that enables easy attachment of the tag to different kinds of objects. The second part is the RFID reader that is a comparatively larger device which communicates with RFID tags to enquire about the stored data. The technology can operate at different frequencies between 30 kHz and 6.8GHz. There are regulations in different parts of the world regarding the spectrum that can be used and the maximum power levels at which these devices can operate. This limits the range of operation as well as availability of particular devices in specific parts of the world (governed by regulation about use of particular frequencies by RFID). Different devices (Tag and reader combination) are available from different vendors and each of the devices is suitable for different applications. For example, devices operating at lower frequency are limited in the range at which they can operate but have the advantage of being able to use them with non-conductive materials and water based products. Devices operating at higher frequencies, though have the advantage of longer ranges, require higher power levels (typically active tags) and are more directed in nature.

Below, the key characteristics of RFID technology, as applicable to airline industry are summarized, which should help put the technology in the right perspective.

- RF sensing means no line of sight is required between the RFID reader and the RFID tags. When passenger's baggage is in ramp area and getting connected to another airline's flight, the time available to send the bags is called MCT (Minimum Connecting Time). The MCT is usually only 30-45 minutes, which is very critical. In fact, RFID tags for interlined bags can be embedded in the bags being transferred. The implication of this is that a RFID system placed at the entrance of a baggage makeup area can instantaneously find out information about all the RFID tagged bags for interline transfer, packaged / hidden within a large container and load them in time.

- RFID technology can work at longer ranges (up to 300 feet for active tags and up to 30 feet with passive tags) compared to bar codes (few centimetres), which can give advance information about the bags that are expected to be transferred from an arrival flight to another departure flight.

- RFID tags, which are passive like bar codes, can be permanently affixed to a loyalty program member's bag. This means that these bags, even if misplaced can be found out. Passive tags are much cheaper, as they don't require any power source. When enquired by a RFID reader, these tags (chips) derive power from the enquiring RF signal and respond back with the data stored in the tags.

- RFID tags can store larger amount of data about the object. This can range from few bits to few MB (typically 32-256 bits for passive tags and 1MB for active tags).

The International Air Transport Association (IATA) has taken measures to Standardize this and RFID space currently suffers from lack of standardization.

One of the major problems with large scale RFID adoption is the lack of standardization across many fronts, ranging from the different data formats used, to interoperability between RFID readers and tags from different vendors, to interference problems between RFID products from different manufacturers. To overcome such problems several standardization activities have started. The key standardization bodies that are working on these issues include the American National Standards Institute, the International Organization for Standardization, Global Tag (joint initiative of EAN International and the Uniform Code Council) and MIT's AIDC (quite actively working toward its de facto standard) and IATA. The International Air Transport Association (IATA) recently voted in favour of using 13.56 MHz frequency for RFID airline baggage applications and has established a Radio Frequency Working Group (RFWG) to oversee the introduction of 13.56 MHz applications into the airline business.

2.4 Bar Coding and RFID

Radio Frequency Identification (RFID) is the major advance in baggage handling technology that has emerged over the last few years. While only a handful of airports around the world are using RFID, the technology is gaining momentum as an efficient way to optimize the baggage handling process beyond conventional technology based on bar-coded baggage tags. RFIDs ascension as the preferred baggage tracking technology can largely be attributed to its ability to provide virtually perfect end-to-end sorting, tracking and tracing. Because bar code-based systems require a line-of-sight read by a laser, damaged and folded-under bag tags result in read accuracies of only 85 to 90 percent. The remaining 10 to 15 percent leaves a wide margin for error in matching bags to the right passenger and flight.

RFID-based systems, because they use radio frequency waves and do not require a line of-sight read, are able to read bag tags from virtually any vantage point, even those lying underneath a bag. As such, RFID-based systems avoid the potential for lost luggage that can occur with bar code-based systems, ultimately increasing passenger satisfaction.

In airports with significant passenger volumes, such as Las Vegas - McCarran International (LAS) which moves 65,000 bags a day, RFID is an increasingly compelling technology. McCarran is the first airport in the world to use an Ultra High Frequency (UHF) RFID system for the identification, tracking and tracing of all outbound baggage. UHF RFID is considered the leading edge in secure radio frequency systems.

Pandit Pankajnarayan (2004), in his study, revealed that airlines, on an average, lose about four bags for every 1,000 passengers carried. For 1.95 billion passengers, who travelled in year 2002, this translates to 7.2 million lost bags. The compensation is paid @ US$ 20 per kilo of checked baggage. Assuming a baggage allowance of 20 Kg, this translated to a figure of $ 2.8 billion on payment of compensation for loss of baggage.

Putting the accuracy of the 40,000 bag test in perspective, the figures represent a problem with 80 bags with RFID compared to as many as 8,000 bags with bar codes (as summarized below in Pankajnarayan's paper : use of RFID for Airlines).

Errors per 40,000 bags	RFID	Bar Code
Worst Case	1,320 (96.7%)	8,000 (80%)
Best Case	80 (99.8%)	6,000 (85.0%)

It is important to realize that when a bag tag is not read, they are manually identified and routed to the correct flight. But manual handling delays bags and they do not always get to the aircraft before departure and manual methods are prone to error. That is why, when you fly to Los Angeles, which has a three letter IATA acronym LAX, your bags might end up in Lagos, which has a three letter acronym as LOS. Further, the primary reason how a baggage is lost is when the baggage tag comes off, due to entanglement with conveyor belts or any other sharp objects, thereby losing the bag's identity. Conversely, RFID tag struck on inner portion of bag can help in correct loading and in its identification in the event of baggage tag coming off.

2.5 Key Benefits of RFID for Industrial Applications

- Enhanced Passenger Security.
- Improved Baggage / inventory visibility
- Reduced operating costs
- Improved customer service and satisfaction

2.6 RFID Baggage Tagging System as a solution – McCarran International Airport

McCarran International Airport handles nearly 70,000 passengers and more than 460 flights each day, making it the 7th busiest airport in the USA, according to Airports Council International. With two terminals, 93 gates and an ever-increasing passenger population intrigued by the glamour of Las Vegas, the airport has reported annual double-digit growth in recent years. This staggering increase, along with Transportation Security Administration (TSA) mandates for improved airport safety since September 11th, prompted airport officials to seek more efficient passenger check-in and screening passengers and employees.

Airport officials conducted extensive research to discover alternatives to conventional baggage handling and tracking processes. They soon discovered the numerous advantages of RFID, UHF Radio Frequency Identification smart-label technology. They then selected an

EPC-compliant RFID technology and a pioneer solution provider in the industry, to design and implement the solution for their passenger safety and satisfaction dilemma.

Matrics Incorporated, an industry leader in RFID based systems and McCarran International Airport set out to create an efficient, cost-effective, and accurate baggage tracking system that supported the Transportation Security Administration's (TSA) objective to screen all passenger baggage. Together, the team developed a new process to automatically track all passenger bags through in line explosive detection and screening equipment, ensuring safe passage for the airport's millions of customers.

The new system provides McCarran with nearly 100% accurate baggage tracking as well as end-to-end baggage visibility. RFID tags are printed and attached at the ticket counter. Each tag carries a unique identifier that is read while the bag is transported to conveyor belts to route it to screening machines and then on to the appropriate aircraft.

2.7 The Outcome

Today, McCarran International Airport is serving more passengers than ever, more quickly than ever. Despite the ever-growing airport traffic, officials are delighted to report a continuous and significant increase in passenger satisfaction.

According to Randall Walker – Director for McCarran International Airport this is truly a win-win for everyone: the traveller, the airport, the TSA, and the airline. This new process enables travellers to be safer, while reducing the incidence of lost baggage and ensuring that screened bags are delivered to the right location at the right time.

2.8 Systems used at Heathrow Airport.

London Heathrow Airport is the busiest Airport in the world having five Passenger Terminals to serve 66 million (2004 figures) annually and handles 47 million bags per year. The Baggage handling system in operation at Heathrow is one of the most advanced, sophisticated and reliable systems in operation.

At Heathrow, check-in will look at bit different and bags will be assigned priorities for their passage through the system: for instance, if a bag is checked in early, it will be moved to an early –bag store in the building's basement. On-time bags and time-critical items will be assigned and routed accordingly.

At check-in, a time critical item will be sent down the chute very early, directly to the aircraft.

The transfer baggage system inherited in 2001 featured Destination Coded Vehicles (DCVs) equipped with tilt trays, which carry bags through the 9-mile tunnel. Tilt tray sorters are ideal for handling larger and irregularly shaped items, and provide a facility for the re-circulation of packages or boxes etc. One of the key features of the DCV system was its reliability in tracking which enabled us to comply with legislation without having to invest excessively in complex baggage monitoring equipment. The equipment is designed to produce high levels of throughput with a controlled sorting action designed to minimise damage (Airports International)

At check-in, an item is placed on the conveyor in the usual way, after which it is automatically x-rayed before being loaded into a container for automatic storage and retrieval. However, the procedure used at BIA is bit different. All the screening of baggage take place at the beginning before the customs and check-in and a sticker is pasted to identify the screened baggage. After check-in, the baggage goes directly to the respective carousel, depending on the airline and will be scanned for loading to the correct ULD.

2.9 Two step check-in

In the two step process of passenger check-in available at 'Anchorage' airport-USA, first the passengers can either check-in on line, from home for example, or print out the boarding pass, or they can use the self –service Instant Travel Machines (ITM) [self service kiosks] which has a passport reading capability. For step 2, passengers then take their baggage to any of the baggage drop – off points, where an agent scans the boarding pass, tags are printed and attached to the luggage and the passenger is then able to proceed to the Gate.

2.10 Automation of BHS where it became a failure

Automated Baggage Handling System turned to be a major failure at Denver International Airport, USA which launched the project in 1995 by anticipating that baggage movement would be simple and easier.

According to Veronica Steven, a lead baggage handler for United Airlines and President of the union local that represents United's 1,300 or so baggage handlers in Denver, automation always looks good on paper but sometimes you need real people. However, today airline economics has changed a lot and the airlines that were flourishing earlier are now struggling and looking for ways to save money now like what the United Airlines did at Denver by shutting down the computerized baggage handling system.

Technology on the other hand has brought many changes. Decentralization and mobile computing technology have taken over just about everything that has led to learn, with just a few clicks the whereabouts of an item in motion can be found with the baggage system. Denver's baggage handling system was a very large, complex, and sophisticated one having several miles of tracks, thousands of small gray carts etc.

But the price tag ballooned along with glitches. The investor incurred heavy losses due to large cost overrun and due to changes done subsequently to the system and a loss of $1 million a day for several months due to the delay in the date of opening. Later the primer user of the system – United Airline, Denver's busiest airline, used a stripped-down simplified version of the network for its outgoing flights since the airport opened in 1995. It is noted that automation never worked for incoming flights, whose baggage has been moved by handlers from the beginning. No other airline tried to use the error- prone system at all.

Ultimately, due to the pressure to cut down costs as the airline struggles to emerge from bankrupting, along with sharply rising fuel prices forced the issue. At last, turning off the computer and reverting to the old-fashioned use of human beings who drive baggage carts from gate to gate, the way things are done at most airports, which will save $1 million a month in maintenance costs was chosen by the authorities.

2.11 Implications on the Baggage re-claim

Sizing the Baggage re-claim area appropriately will improve the passenger comfort and will enhance the operational efficiency. In order to ensure a properly designed and adequately sized Baggage re-claim area, the recommendations given in the IATA Airport Development Reference Manual- 8 th Edition, to be adhered / followed. With 25 % or more extra passengers and all trying to be the closest to the reclaim belt will require longer belts or carousels that demands spacious halls to allow for new potential peak flows.

At JFK New York they have taken the view that belt designed for 747-400 will be sufficient for the A 380 in the initial configuration given the increased off load times. A significant problem only arises when a terminal has belts designed for smaller aircrafts.

The dilemma here is not whether to make all reclaims bigger, as this would have an unreasonable impact on area and cost, it would rather be recommended that certain belts suitable for these numbers of passengers are installed / modified. The question again is how many and should they cater for the next capacity jump to 850 seat aircraft.

The advent of A 380 s goes hand in hand with the increased use of hubs and hence greater transfer traffic. This will mean additional requirement to accommodate passenger movement and more facilities, including transfer lounges and transfer baggage systems.

2.12 The existing Baggage Handling System at BIA

The BIA uses a Baggage Handling System that require the use of a bar coded bag tag on each piece of baggage in order to be scanned the same, when it arrives to the respective Baggage Carousel, before loading them to the respective containers which are called Unit Local Devices (ULDs).

However, in the event of failure of the airline Departure Control System (DCS), bag tags cannot be printed and lack of a bar coded tag means that the bag cannot be routed through the normal path. The solution is the use of fallback Sortation Tags, bar coded with a number representing the loading location within the sorting system for the bag. This number can be read by the Baggage Scanning System, which helps the bag to be loaded to the correct ULD.

The automated bar code Scanning System used at BIA for Baggage reconciliation is obviously far more superior, efficient and effective than the previously used manual bag tag reading system.

However, the present system is not the best method to handle baggage as the mishandling of baggage may occur mainly due to the shortcomings in the existing bar code scanning system.

Mishandling of baggage occur due to the following reasons.

1. Poor Print quality of bag tags.
2. Bag tagging errors at check-in.
3. Due to torn-off bag tags.
4. Late acceptance of bags.
5. Mis-sorting, mis-reading or mis-loading.
6. Overlooking and not loading the bag.
7. Baggage transfers due to late arriving connections.

However, the possibilities are very remote in the case of (1), (2) and (5) of above at BIA, according to the Ground Handling Agent, Sri Lankan Airlines Ltd.

2.13 Mishandled / Lost Baggage

The aim and challenge in Baggage Handling process is to send the bag to the gate before the passenger board the aircraft in "Check-in" process and to send the bag to the carousel – claim area before the passenger's presence there.

However, this cannot be achieved in all cases as a result of mishandling of baggage due to the reasons given above.

The number of mishandled baggage of departing passengers (Sri Lankan Flights only) is given in the (Table A – 6) .

The LOS (Level of Service) specified by the ground-handling agent - Sri Lankan Airlines is 3 bags per 1000 departing passengers.

Considering the industry accepted ratio of 1.5 Bags / Passenger, the number of passengers

$$\text{departed} = \frac{\text{Number of Baggage Uplifted (Average)}}{1.5}$$

$$= \frac{124{,}726}{1.5} = 83{,}151$$

$$\begin{array}{l}\text{Number of bags mishandl} \\ \text{Per 1000 passenger}\end{array} = \frac{267}{83{,}151} \times 1000$$

$$= 3.2 \text{ bags per 1000 passengers.}$$

Note : Average is 267 Baggage per 124,726 bags uplifted. (Refer Table A – 6)

According to the industry accepted standard of measuring mishandled bags per 1,000 departing passengers, the value at BIA is 3.2 bags per 1000 departing passengers (for UL passengers only).

	Industry Standard	SLA – LOS Defined	Actual LOS
Number of possible Baggage mishandled per 1000 passengers	**4**	**3**	**3.2**

Thus, the actual level of service, in the case of mishandled baggage, is slightly above the LOS defined by the Sri Lankan Airlines, but below the industry standard.

2.14 Impact of Baggage Handling System by the operation of NLA -Airbus A 380

The operation of NLA (Airbus A380 Super jumbo), which is a wide-bodied, double-decked aircraft, is expected to have a heavy impact on the design and operation of the Baggage Claim Area and the sizing of Baggage Claim Device. The use of two claim devices – one for each aircraft deck is suggested and shown to have a potential to reduce the claim area requirement. {De Barros and Wirasinghe (2004) }

According to De Barros (2004) the separation of passengers and bags during the flight requires a way to return the baggage to passengers in an efficient manner after the flight is over. Since the process of unloading baggage is much more complicated than unloading passengers, the match cannot be done right at the aircraft door. The baggage is thus brought to a mechanical display at the terminal, where passengers can retrieve it.

The introduction of NLA is adding to the problem of accommodating more space in the Baggage Claim Area and large claim devices as the size of the aircraft is increased. This in turn leads more space requirement in Passenger Terminal Buildings and triggers actions like Terminal expansions to ensure more space. Therefore, with NLA Operations, more passengers and correspondingly more bags needing accommodation while waiting for a match will result in the increase in the area requirement and/or a decrease in the level of service. It is imperative that the passengers be directed to the exact device where their bags will be displayed. For this reason, the current practice is to use only one claim device for a given flight. However, existing claim devices at the great majority of existing airport terminals will not be enough for the amount of passengers and bags carried by NLA. At those terminals, it may be imperative to use two devices for an NLA flight. Fortunately, the NLA will feature two different passenger decks, allowing the baggage to be separated between upper and lower deck.

However, this demands the segregation of baggage according to the seat or level each passenger is assigned will also need separate ULDs for storing baggage of upper deck and lower deck passengers. This will lead to more aircraft turnaround times due to more time taken for processing of baggage and related ground handling operations besides the obvious extra time taken due to a higher number of passengers. For new airports, however, the question remains whether the use of two short devices would be more efficient than one long device.

De Barros (2004) has investigated this in his study among other things. In his paper he has used his model to analyse the possible scenarios brought up by the NLA and to investigate the solutions that have been suggested such as the use of two claim devices.

If new baggage belts of sufficient capacities are to be introduced at any airport, exclusively for NLA s (A 380 s) in the existing Baggage claim area it is important to re-define the Claim Area so that levels of service (passenger comfort) in terms of area per passenger is ensured.

According to De Barros (2004) the first significant attempt to model the passenger and baggage claim was made by Barbo (1967) and Horonjeff (1969). These works attempted to determine the maximum accumulation of bags on the claim device using deterministic queuing theory. The accumulation of bags at any time on the device is simply the difference between the number of bags arrived and the number departed.

According to De Barros and Wirasinghe (2004), the use of two devices instead of one reduces the total length requirement, thus reducing the need for physical space. The use of two separate devices is only possible if some sort of criterion is used to separate the bags when they are loaded into the aircraft. Since NLA features two passenger decks, this would be an obvious choice with a low likelihood of confusing passengers. Passengers would be directed to the correct device according to the flight number and the deck on which they travelled. The use of two devices also has the advantage of allowing their use for separate smaller aircrafts when not in use by NLA – an advantage even greater at existing airports.

When the upcoming problem of accommodating NLA passengers and baggage is addressed, as described above, different solutions can be found. The use of two separate claim devices for the two aircraft passenger decks, as suggested above, is shown to be more space efficient, in addition to allow for more flexibility.

However, for this arrangement to work properly, it is necessary to fully separate the baggage at the originating airport. Co-ordination between the airlines operating the NLA and the airport authorities is fundamental to allow such separation. Further, it might be needed to reach a consensus among various parties such as Airlines, Airports and Ground Handlers who are going to be affected by A 380 operations. However, those Airports which possess new larger belts designed for A 380 operations will not be interested in such a move which results in making it difficult to standardise such processes unless a regulator such as IATA comes out with a required standards / recommendations

The adjustment of the customs service rate also showed to be an efficient way to reduce the need for physical space and the consequent need for expansion in existing terminals. This procedure is very difficult to be agreed upon by all parties involved such as airlines, customs authority and airport management. However, if all costs and benefits are properly distributed among the parties involved, the final result can be much better for the airport system as a whole. {De Barros and Wirasinghe (2004)}

As described above, Baggage Handling is one of the key pinch areas that will be affected by the new peak flows that will occur when one or more A 380 flights land. One of the key elements of the baggage handling facility is its make up lines. These are the areas, beside the offload & sortation conveyors, designated to each flight for baggage dolly trains. The maximum length of these has until now been determined by the largest aircraft i.e. the 747-400 and optimum system throughputs.

It has been noted that these make up lines now need to be 25 % bigger in the medium term and 40 % in the medium to long term. Business objectives could be set to improve system reliability, capacity, throughputs, operation, maintenance and management. This will require changes to baggage handling layouts, staff accommodation utilising new baggage technology, rationalising welfare to increase flight make up area and consideration for increased bag storage within transfer facilities or changes in operation of the current layouts. This could take the form of utilising two make up lines for one A 380 flight. These areas are worked to capacity at peak times. The commitment of two lines to one flight could compromise operations and even jeopardise turn around times. {De Barros and Wirasinghe (2004)}

3. Methodology

The scope of the study of improving the BHS Infrastructure at BIA by studying on the optimum utilisation of Baggage Belts is limited to Arrival Baggage Handling system or Arrival Baggage re-claim devices.

In the case of study at BIA, it was assumed that the bags will be considered to be loaded & unloaded uninterruptedly as per the Graph 3-1 shown under 'Methodology'.

In this study the optimum values obtained are compared & matched with the present peak hour aircraft mix and the corresponding values (forecast) in year 2015, by considering 3 scenarios such as Low, Medium and High growth rates and thereby decide on what additions / improvements to be done in meeting the said future demand.
The impact of NLA: Airbus A 380 is also considered/ assessed in this study / analysis.

There are three steps in the methodology to achieve the desired objectives.

Step 1: Data Collection
Step 2: Data Analysis and Interpretation
Step 3: To develop a suitable model to meet the requirements described under objectives.

3.1 Optimum utilization of Baggage Belts – Solution Techniques used.

In finding the optimum number of aircrafts that should be assigned to each Baggage Belt the 'knapsack / Fly-away –kit Model' available under the subject 'Dynamic Programming' was used.
Modelling of the problem under the above has been given and described under 3.4 (Step 3) below.
Both 'Optimum solutions' and 'Alternative Solutions (optimum)' have been found where relevant and feasible and the values are tabulated at respective locations, as shown.

3.2 Step 1: Data Collection

The Data required for the study are

- Baggage Belt Capacities in terms of kg and / or equivalent 25 kg bags. (Table A - 7)

- Different Aircraft types operating to Colombo and their capacities considering the load factors. [Passenger & baggage capacities] (Table A –8)
- Baggage loading rate to the baggage belt.
- Baggage unloading rate from the belt (baggage re-claim rate from the belt)

3.3 Step 2: Data Analysis and Interpretation

Assume

1). Constant Bag loading rate $= a$

2). Constant Bag Unloading rate $= D$ and $a > D$

Y_{max} = Maximum Capacity of the Belt.

Y = Number of Bags which can be fed on to the Belt at a time

t_0 = Time taken to load all the bags (of an aircraft) to the Belt

t_1 = Time taken to unload all the bags (of an aircraft) from the Belt.

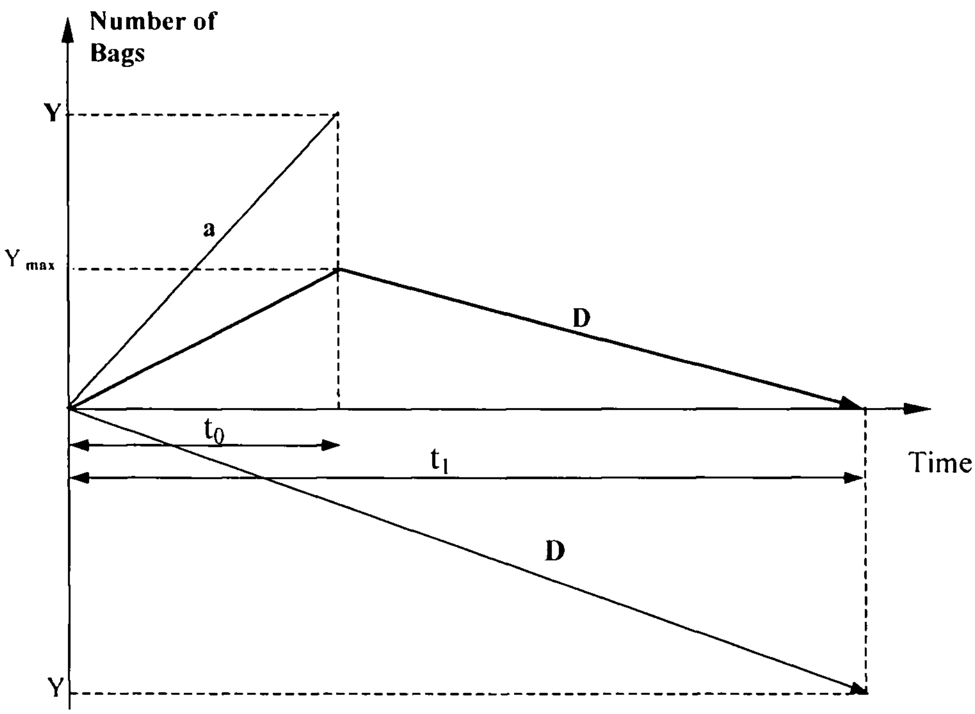
As per Graph 3 – 1

$Y = t_0 a \quad = t_1 D$

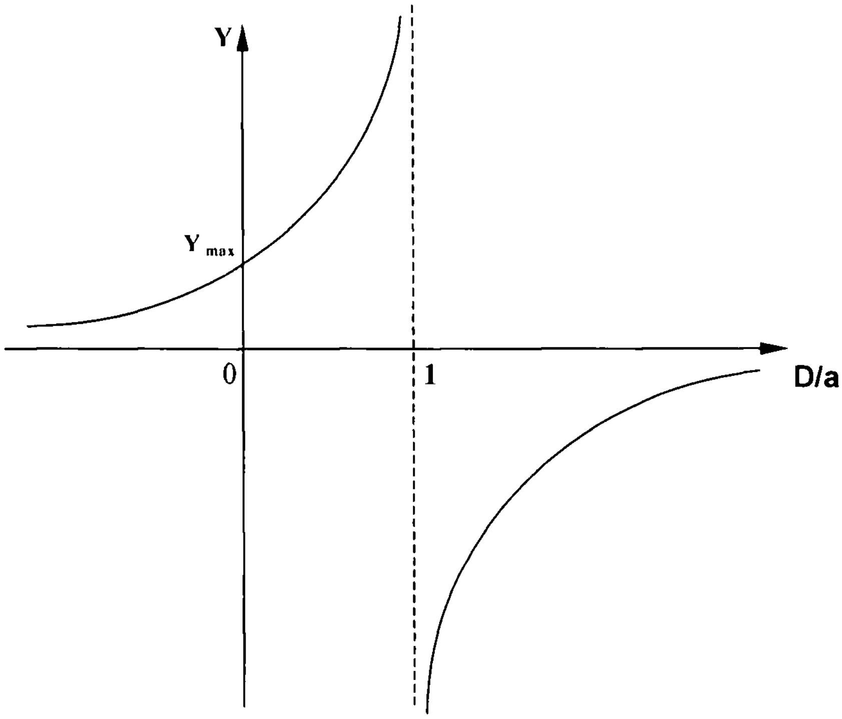
$Y_{max} \quad = (t_1 - t_0) D$

$Y_{max} \quad = Y (1 / D - 1 / a) D \quad = Y (1 - D/a)$

$Y \quad = Y_{max} / (1 - D / a)$ .... (1)



Graph 3-1: Number of Baggage vs. Time



Graph 3-2: Number of Bags fed onto the Belt vs D / a

3.4 Step 3: To develop a suitable model to meet the requirements described under objectives.

A specific model called Knapsack / Fly-away-kit Model is used to describe the above situation of allocating a scarce resource under constraints.

Knapsack modelling for Baggage belt utilization / allocation

Aircraft [Item i]	Weight w_i of baggage	Pax Capacity [revenue r_i] (Nos.)
N = 1	w_1	440
J = 2	w_2	320
L = 3	w_3	240
M = 4	w_4	200
S = 5	w_5	120

We take Passenger (pax.) Capacity (or the Number of passengers served) as the expected return function from the resource allocation. It is required to maximize the return.

Effective Capacity of Belts

Using Y = Y max / (1 - D/a) we calculate the effective capacity of each belt. Assume D/a = 7/10

Belt	Actual Capacity (Number of 25 kg equivalent baggage)	Effective Capacity (Number of 25 kg equivalent baggage)
1	134	446
2	134	446
3	134	446
4	260	866
5	400	1333

1. Stage i represented by item i = 1,2,3,4,5
2. Alternatives at stage i represented by m_i, number of units of item i (aircraft type)
3. m_i = 0,1,2..............[W / w_i] ; largest integer less than or equal to[W / w_i]
4. The associated return / priority of each item i are r_i

   Associated return is $r_i m_i$

Thus the problem

Maximize Z = $r_1m_1 + r_2m_2 + \ldots\ldots\ldots + r_5m_5$ ....(a)

$w_1m_1 + w_2m_2 + w_3m_3 + \ldots\ldots + w_5m_5 <= W$

$m_1, m_2, \ldots\ldots m_5 >= 0$

m_i = 0,1,2,3,...[W / w_i]

Define state at stage i representing x_i = the total weight assigned to Belts 1,2,3,4,5

x_i = W

Define $f_i(x_i)$ = Maximum return for stages i , i+1 , ..., n at given state x_i

By Definition

$x_i = w_i m_i + x_{i+1}$

$x_{i+1} = x_i - w_i m_i$

$f_i(x_i) = \text{Max} \{ r_i m_i + f_{i+1}(x_{i+1}) \}$ .... (1)

m_i = 0,1,......, (W / w_i)

$x_i <= w$

$$f_i(x_i) = \max_{m_i} \{ r_i m_i + f_{i+1}(x_i - w_i m_i) \} \ldots\ldots\ldots\ldots (2)$$

$m_i = 0, 1, \ldots\ldots, (W / w_i)$

$x_i <= w$

For the calculation the following table shows w_i and r_i values taken from Table A - 8.

Aircraft	**i**	**w_i (Number of Baggage)**	**r_i (Nos.)**
N	1	660	440
J	2	480	320
L	3	360	240
M	4	300	200
S	5	180	120

Using equation (2) and the table we define the five stages as:

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \} \ldots\ldots\ldots\ldots (A)$$

$m_5 = 0,1,2,3, \ldots\ldots\ldots\ldots, W / w_5$

$$f_4(x_4) = \max_{m_4} \{200\, m_4 + f_5(x_4 - 300\, m_4\} \ldots\ldots\ldots\ldots (B)$$

$m_4 = 0,1,2,3, \ldots\ldots\ldots\ldots, W / w_4$

$$f_3(x_3) = \max_{m_3} \{240\, m_3 + f_4(x_3 - 360\, m_3\} \ldots\ldots\ldots\ldots (C)$$

$m_3 = 0,1,2,3, \ldots\ldots\ldots\ldots, W / w_3$

$$f_2(x_2) = \max_{m_2} \{320\, m_2 + f_3(x_2 - 480\, m_2\} \ldots\ldots\ldots\ldots (D)$$

$m_2 = 0,1,2,3, \ldots\ldots\ldots\ldots, W / w_2$

$$f_1(x_1) = \max_{m_1} \{440\, m_1 + f_2(x_1 - 660\, m_1\} \ldots\ldots\ldots\ldots (E)$$

$m_1 = 0,1,2,3, \ldots\ldots\ldots\ldots, W / w_1$

We can solve equation (A) to (E) in an iterative manner to get the values of m_i^*, which gives the number of aircrafts in each type (mix) for the maximum return function.

4. Calculation

To demonstrate the calculation the following examples compute optimum mix aircrafts and Maximum return for each baggage belt.

4.1 Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/a = 0.7

Belt 1 :

W	w_5	W / w_5
446	180	2

$$f_5(x_5) = \max_{m_5} \{ 120 m_5 + 0 \}$$

$$180 m_5 <= X_5$$

m_5 = 0,1,2

STAGE 5

	W / w_5 =	
		0
		60
180	1	180
		300
180	2	360

	m_5			Optimum	
X_5	0	1	2	$f_5(x_5)$	m_5^*
0	0			0	0
60	0			0	0
180	0	120		120	1
300	0	120		120	1
360	0	120	240	240	2

W	w_4	W / w_4
446	300	1

$$f_4(x_4) = \max_{m_4} \{ 200 m_4 + f_5(x_4 - 300 m_4) \}$$

$$300 m_4 <= x_4$$

m_4 = 0,1

STAGE 4

	W / w_4 =	
		0
300	1	300
		360

	m_4		Optimum	
X_4	0	1	$f_4(x_4)$	m_4^*
0	0		0	0
300	120	200	200	1
360	240	200	240	0

W	w_3	W / w_3
446	360	1

$$f_3(x_3) = \max_{m_3} \{ 240 m_3 + f_4(x_3 - 360 m_3) \}$$

$$360 m_3 <= x_3$$

m_3 = 0,1

STAGE 3

	W / w_3 =	
		0
360	1	360

	m_3		Optimum	
X_3	0	1	$f_3(x_3)$	m_3^*
0	0		0	0
360	0	240	240	1

$X_3 = 360$ gives maxm $m_3 = 1$

$X_4 = X_3 - w_3 * m_3$

$X_4 = 360 - 360 * 1$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 1 is maximized when $m_3 = 1$, $m_4 = 0$, $m_5 = 0$

Thus, Belt 1 capacity is optimized with 1 no. Large Aircraft

As W = 446 for Belt 2 and Belt 3 the optimization would be as same as Belt 1.

Optimum Solution	**m_3**	**m_4**	**m_5**
Belt 1	**1**	0	0
Belt 2	**1**	0	0
Belt 3	**1**	0	0

Belt 4:

W	w_5	W / w_5
866	180	4

$$f_5(x_5) = \max_{m_5} \{ 120 m_5 + 0 \}$$

$$180 m_5 <= X_5$$

M_5 = 0,1,2,3,4

W / w_5 = 0

		0
		60
		120
180	1	180
		300
180	2	360
		480
180	3	540
		600
		660
180	4	720

STAGE 5

	m_5					Optimum	
X_5	0	1	2	3	4	$f_5(x_5)$	m_5^*
0	0					0	0
60	0					0	0
120	0					0	0
180	0	120				120	1
300	0	120				120	1
360	0	120	240			240	2
480	0	120	240			240	2
540	0	120	240	360		360	3
600	0	120	240	360		360	3
660	0	120	240	360		360	3
720	0	120	240	360	480	480	4

W	w_4	W / w_4
866	300	2

$$f_4(x_4) = \underset{m_4}{\text{Max}} \{ 200\, m_4 + f_5(x_4 - 300 m_4) \}$$

$$300\, m_4 <= x_4$$

M_4 = 0,1,2

W / w_4	=	
		0
		120
		180
300	1	300
		360
		480
300	2	600
		660
		720

STAGE 4

	m_4			Optimum	
X_4	0	1	2	$f_4(x_4)$	m_4^*
0	0			0	0
120	0			0	0
180	120			120	0
300	120	200		200	1
360	240	200		240	0
480	240	320		320	1
600	360	320	400	400	**2**
660	360	440	400	440	1
720	480	440	400	480	0

W	w_3	W / w_3
866	360	2

$$f_3(x_3) = \underset{m_3}{\text{Max}} \{ 240\, m_3 + f_4(x_3 - 360 m_3) \}$$

$$360\, m_3 <= x_3$$

M_3 = 0,1,2

STAGE 3

W / w_3	=	
		0
		180
360	1	360
		480
		660
360	2	720

	m_3			Optimum	
X_3	0	1	2	$f_3(x_3)$	m_3^*
0	0			0	0
180	120			120	0
360	240	240		240	1
480	320	240		320	0
660	440	440		440	0,1
720	480	480	480	480	**0,1, 2**

W	w_2	W / w_2
866	480	1

$$f_2(x_2) = \underset{m_2}{\text{Max}} \{ 320 m_2 + f_3(x_2 - 480 m_2) \}$$

$$480\, m_2 <= x_2$$

M_2 = 0,1

STAGE 2

W / w_2	=	
		0
480	1	480
		660

	m_2		Optimum	
X_2	0	1	$f_2(x_2)$	m_2^*
0	0		0	0
480	320	320	320	**1**
660	440	440	440	**0,1**

W	w_1	W / w_1
866	660	1

$$f_1(x_1) = \max_{m_1} \{440m_1 + f_2(x_1 - 660m_1)\}$$

$660\, m_1 <= x_1$

$M_1 = 0,1$

W / w_1	=	0
660	1	660

STAGE 1

	m_1		Optimum	
X_1	0	1	$f_1(x_1)$	m_1^*
0	0		0	0
660	440	440	440	**0, 1**

$X_1 = 660$ gives maxm $m_1 = 1$

$X_2 = X_1 - w_1 * m_1$
$X_2 = 660 - 660 * 1$

$X_2 = 0$ gives maxm $m_2 = 0$

$X_3 = X_2 - w_2 * m_2$
$X_3 = 0 - 480 * 0$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$
$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$
$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 4 is maximized when $m_1 = 1, m_2 = 0, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 4 capacity is optimized with 1 (one) New Large Aircraft

Alternative solutions fro Belt 4 when D/a = 0.7

$X_1 = 660$ gives $m_1 = 0$

When $m_1 = 0$; $X_1 = 660$

$X_2 = X_1 - w_1 m_1 = 660 - 660 \times 0 = 660$

$X_2 = 660$ gives $m_2 = 0$; $m_2 = 1$

Case 1. When $m_2 = 0$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 0 = 660$

$X_3 = 660$ gives $m_3 = 0$; $m_3 = 1$

Case 1.1. When $m_3 = 0$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 0 = 660$

$X_4 = 660$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 660$

$X_5 = X_4 - w_4 m_4 = 660 - 300 \times 0 = 660$

$X_5 = 660$ gives $m_5 = 2$

Case 1.2. When $m_3 = 1$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 1 = 300$

$X_4 = 300$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 300$

$X_5 = X_4 - w_4 m_4 = 300 - 300 \times 1 = 0$

$X_5 = 0$ gives $m_5 = 1$

Case 2. When $m_2 = 1$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 1 = 180$

$X_3 = 180$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 180$

$X_4 = X_3 - w_3 m_3 = 180 - 360 \times 0 = 180$

$X_4 = 180$ gives $m_4 = 0$

When $m_4 = 0$; $X_4 = 180$

$X_5 = X_4 - w_4 m_4 = 180 - 300 \times 0 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_1	m_2	m_3	m_4	m_5
Optimum Solution	1	0	0	0	0
Alternative Solutions	0	0	0	1	2
	0	0	1	1	1
	0	1	0	0	1

Belt 5:

W	w_5	W / w_5
1333	180	7

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$

$$180\, m_5 <= X_5$$

$m_5 = 0,1,2,3,4,5,6,7$

STAGE 5

W / w_5 =			X_5	m_5: 0	1	2	3	4	5	6	7	Optimum $f_5(x_5)$	Optimum m_5^*
		0	0	0								0	0
		60	60	0								0	0
		120	120	0								0	0
180	1	180	180	0	120							120	1
		240	240	0	120							120	1
		300	300	0	120							120	1
180	2	360	360	0	120	240						240	2
		420	420	0	120	240						240	2
		480	480	0	120	240						240	2
180	3	540	540	0	120	240	360					360	3
		600	600	0	120	240	360					360	3
		660	660	0	120	240	360					360	3
180	4	720	720	0	120	240	360	480				480	4
		780	780	0	120	240	360	480				480	4
		840	840	0	120	240	360	480				480	4
180	5	900	900	0	120	240	360	480	600			600	5
		960	960	0	120	240	360	480	600			600	5
		1020	1020	0	120	240	360	480	600			600	5
180	6	1080	1080	0	120	240	360	480	600	720		720	6
		1200	1200	0	120	240	360	480	600	720		720	6
180	7	1260	1260	0	120	240	360	480	600	720	840	840	7
		1320	1320	0	120	240	360	480	600	720	840	840	7

W	w_4	W / w_4
1333	300	4

$$f_4(x_4) = \underset{m_4}{\text{Max}} \{ 200\, m_4 + f_5(x_4 - 300 m_4) \}$$

$$300\, m_4 <= x_4$$

M_4 = 0,1,2,3,4

STAGE 4

W	w_4	W / w_4 =
		0
		120
		180
		240
300	1	300
		360
		480
300	2	600
		660
		720
		840
300	3	900
		960
		1080
300	4	1200
		1320

	m_4					Optimum	
X_4	0	1	2	3	4	$f_4(x_4)$	m_4^*
0	0					0	0
120	0					0	0
180	120					120	0
240	120					120	0
300	120	200				200	1
360	240	200				240	0
480	240	320				320	1
600	360	320	400			400	2
660	360	440	400			440	1
720	0	440	400			440	1
840	480	560	520			560	1
900	600	560	520	600		600	0,3
960	600	560	640	600		640	2
1080	720	680	640	720		720	0,3
1200	720	800	760	720	800	800	1,4
1320	840	800	880	840	800	880	2

W	w_3	W / w_3
1333	360	3

$$f_3(x_3) = \underset{m_3}{\text{Max}} \{ 240\, m_3 + f_4(x_3 - 360 m_3) \}$$

$$360\, m_3 <= x_3$$

M_3 = 0,1,2,3

STAGE 3

W	w_3	W / w_3 =
		0
		180
360	1	360
		480
		660
360	2	720
		840
		960
360	3	1080
		1320

	m_3				Optimum	
X_3	0	1	2	3	$f_3(x_3)$	m_3^*
0	0				0	0
180	120				120	0
360	240	240			240	1
480	320	240			320	0
660	440	440			440	0,1
720	440	480	480		480	2
840	560	560	480		560	0,1
960	640	640	600		640	0,1
1080	720	680	720	720	720	0,2,3
1320	880	880	880	840	880	0,1,2

W	w_2	W / w_2
1333	480	2

$$f_2(x_2) = \max_{m_2} \{ 320m_2 + f_3 (x_2 - 480m_2) \}$$

$$480 m_2 <= x_2$$

M_2 = 0,1,2

W / w_2 = 0
480 1 480
660
480 2 960
1320

STAGE 2

	m_2			Optimum	
X_2	0	1	2	$f_2(x_2)$	m_2^*
0	0			0	0
480	320	320		320	1
660	440	440		440	0,1
960	640	640	640	640	0,1,2
1320	880	880	880	880	0,1,2

W	w_1	W / w_1
1333	660	2

$$f_1(x_1) = \max_{m_1} \{440m_1 + f_2 (x_1 - 660m_1) \}$$

$$660 m_1 <= x_1$$

M_1 = 0,1,2

W / w_1 = 0
660 1 660
660 2 1320

STAGE 1

	m_1			Optimum	
X_1	0	1	2	$f_1(x_1)$	m_1^*
0	0			0	0
660	440	440		440	1
1320	880	880	880	880	**0,1, 2**

X_1 = 1320 gives maxm $m_1 = 2$

$X_2 = X_1 - w_1 * m_1$
$X_2 = 1320 - 660 * 2 = 0$

$X_2 = 0$ gives maxm $m_2 = 0$

$X_3 = X_2 - w_2 * m_2$
$X_3 = 0 - 480 * 0$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$
$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$
$X_5 = 0 - 300 * 0$
$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 5 is maximized when $m_1 = 2, m_2 = 0, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 5 capacity is optimized with 2 (two) New Large Aircraft

Alternative solutions for Belt 5 when D/a = 0.7

$X_1 = 1320$ gives $m_1 = 0$; $m_1 = 1$

Case 1. When $m_1 = 0$; $X_1 = 1320$

$X_2 = X_1 - w_1 m_1 = 1320 - 660 \times 0 = 1320$

$X_2 = 1320$ gives $m_2 = 0$; $m_2 = 1$; $m_2 = 2$

Case 1.1. When $m_2 = 0$; $X_2 = 1320$

$X_3 = X_2 - w_2 m_2 = 1320 - 480 \times 0 = 1320$

$X_3 = 1320$ gives $m_3 = 0$; $m_3 = 1$; $m_3 = 2$

Case 1.1.1. When $m_3 = 0$; $X_3 = 1320$

$X_4 = X_3 - w_3 m_3 = 1320 - 360 \times 0 = 1320$

$X_4 = 1320$ gives $m_4 = 2$

When $m_4 = 2$; $X_4 = 1320$

$X_5 = X_4 - w_4 m_4 = 1320 - 300 \times 2 = 720$

$X_5 = 720$ gives $m_5 = 4$

Case 1.1.2. When $m_3 = 1$; $X_3 = 1320$

$X_4 = X_3 - w_3 m_3 = 1320 - 360 \times 1 = 960$

$X_4 = 960$ gives $m_4 = 2$

When $m_4 = 2$; $X_4 = 960$

$X_5 = X_4 - w_4 m_4 = 960 - 300 \times 2 = 360$

$X_5 = 360$ gives $m_5 = 2$

Case 1.1.3. When $m_3 = 2$; $X_3 = 1320$

$X_4 = X_3 - w_3 m_3 = 1320 - 360 \times 2 = 600$

$X_4 = 600$ gives $m_4 = 2$

When $m_4 = 2$; $X_4 = 600$

$X_5 = X_4 - w_4 m_4 = 600 - 300 \times 2 = 0$

$X_5 = 0$ gives $m_5 = 0$

Case 1.2. When $m_2 = 1$; $X_2 = 1320$

$X_3 = X_2 - w_2 m_2 = 1320 - 480 \times 1 = 840$

$X_3 = 840$ gives $m_3 = 0$; $m_3 = 1$

Case 1.2.1. When $m_3 = 0$; $X_3 = 840$

$X_4 = X_3 - w_3 m_3 = 840 - 360 \times 0 = 840$

$X_4 = 840$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 840$

$X_5 = X_4 - w_4 m_4 = 840 - 300 \times 1 = 540$

$X_5 = 540$ gives $m_5 = 3$

Case 1.2.2. When $m_3 = 1$; $X_3 = 840$

$X_4 = X_3 - w_3 m_3 = 840 - 360 \times 1 = 480$

$X_4 = 480$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 480$

$X_5 = X_4 - w_4 m_4 = 480 - 300 \times 1 = 180$

$X_5 = 180$ gives $m_5 = 1$

Case 1.3. When $m_2 = 2$; $X_2 = 1320$

$X_3 = X_2 - w_2 m_2 = 1320 - 480 \times 2 = 360$

$X_3 = 360$ gives $m_3 = 1$

Case 1.3.1. When $m_3 = 1$; $X_3 = 360$

$X_4 = X_3 - w_3 m_3 = 360 - 360 \times 1 = 0$

$X_4 = 0$ gives $m_4 = 0$

When $m_4 = 0$; $X_4 = 0$

$X_5 = X_4 - w_4 m_4 = 0 - 300 \times 0 = 0$

$X_5 = 0$ gives $m_5 = 0$

Case 2. When $m_1 = 1$; $x_1 = 1320$

$X_2 = X_1 - w_1 m_1 = 1320 - 660 \times 1 = 660$

$X_2 = 660$ gives $m_2 = 0$; $m_2 = 1$

Case 2.1. When $m_2 = 0$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 0 = 660$

$X_3 = 660$ gives $m_3 = 0$; $m_3 = 1$

Case 2.1.1. When $m_3 = 0$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 0 = 660$

$X_4 = 660$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 660$

$X_5 = X_4 - w_4 m_4 = 660 - 300 \times 1 = 360$

$X_5 = 360$ gives $m_5 = 2$

Case 2.1.2. When $m_3 = 1$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 1 = 300$

$X_4 = 300$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 300$

$X_5 = X_4 - w_4 m_4 = 300 - 300 \times 1 = 0$

$X_5 = 0$ gives $m_5 = 0$

Case 2.2. When $m_2 = 1$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 1 = 180$

$X_3 = 180$ gives $m_3 = 0$

Case 2.2.1. When $m_3 = 0$; $X_3 = 180$

$X_4 = X_3 - w_3 m_3 = 180 - 360 \times 0 = 180$

$X_4 = 180$ gives $m_4 = 0$

When $m_4 = 0$; $X_4 = 180$

$X_5 = X_4 - w_4 m_4 = 180 - 300 \times 0 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_1	m_2	m_3	m_4	m_5
Optimum Solution	**2**	0	0	0	0
	0	0	0	**2**	**4**
	0	0	**1**	**2**	**2**
	0	0	**2**	**2**	0
	0	**1**	0	**1**	**3**
Alternative Solutions	0	**1**	**1**	**1**	**1**
	0	**2**	**1**	0	0
	1	0	0	**1**	**2**
	1	0	**1**	**1**	0
	1	**1**	0	0	**1**

Total maximum return Z for the optimum Aircraft mix has been calculated using the equation

$Z \quad = \quad r_1m_1 + r_2m_2 + \ldots\ldots\ldots\ldots\ldots\ldots + r_5m_5$

and the Z values are shown in Table A –12.

4.2 Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/a = 0.7 and in the absence of NLA: Airbus A 380

Belt No 1, 2& 3.

W	w_5	W / w_5
446	180	2

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$

$$180\, m_5 <= X_5$$

$M_5 = 0,1,2$

		W/w_5 =
		0
		60
180	1	180
		300
180	2	360

STAGE 5

	m_5			Optimum	
X_5	0	1	2	$f_5(x_5)$	m_5^*
0	0			0	0
60	0			0	0
180	0	120		120	1
300	0	120		120	1
360	0	120	240	240	2

W	w_4	W / w_4
446	300	1

$$f_4(x_4) = \max_{m_4} \{ 200\, m_4 + f_5(x_4 - 300 m_4)\}$$

$$300\, m_4 <= x_4$$

M_4 = 0,1

STAGE 4

	m_4		Optimum	
X_4	0	1	$f_4(x_4)$	m_4^*
0	0		0	0
300	120	200	200	1
360	240	200	240	0

W/w_4	=	0
300	1	300
		360

W	w_3	W / w_3
446	360	1

$$f_3(x_3) = \max_{m_3} \{240\, m_3 + f_4(x_3 - 360\, m_3)\}$$

$$360\, m_3 <= x_3$$

m_3 = 0,1

STAGE 3

	m_3		Optimum	
X_3	0	1	$f_3(x_3)$	m_3^*
0	0		0	0
360	0	240	240	1

W/w_3	=	0
360	1	360

X_3=360 gives maxm m_3 =1

$X_4 = X_3 - w_3 * m_3$
$X_4 = 360 - 360 * 1$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$
$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 1 is maximized when $m_3 = 1$, $m_4 = 0$, $m_5 = 0$

Thus, Belt 1 (2 and 3) capacity is optimized with 1 Large Aircraft

Optimum Solution	m3	m4	m5
Belt 1	1	0	0
Belt 2	1	0	0
Belt 3	1	0	0

Belt No 4.

W	w_5	W/w_5
866	180	4

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$
$$180\, m_5 <= X_5$$

m_5 = 0,1,2,3,4

W/w_5 =

		0
		60
		120
180	1	180
		300
180	2	360
		480
180	3	540
		600
		660
180	4	720

STAGE 5

	m_5					Optimum	
X_5	0	1	2	3	4	$f_5(x_5)$	m_5^*
0	0					0	0
60	0					0	0
120	0					0	0
180	0	120				120	1
300	0	120				120	1
360	0	120	240			240	2
480	0	120	240			240	2
540	0	120	240	360		360	3
600	0	120	240	360		360	3
660	0	120	240	360		360	3
720	0	120	240	360	480	480	4

W	w_4	W/w_4
866	300	2

$$f_4(x_4) = \max_{m_4} \{ 200\, m_4 + f_5(x_4 - 300 m_4) \}$$
$$300\, m_4 <= x_4$$

m_4 = 0,1,2

W/w_4 =

		0
		120
		180
300	1	300
		360
		480
300	2	600
		660
		720

STAGE 4

	m_4			Optimum	
X_4	0	1	2	$f_4(x_4)$	m_4^*
0	0			0	0
120	0			0	0
180	120			120	0
300	120	200		200	1
360	240	200		240	0
480	240	320		320	1
600	360	320	400	400	2
660	360	440	400	440	1
720	480	440	400	480	0

W	w_3	W/w_3
866	360	2

$$f_3(x_3) = \max_{\substack{m_3 \\ 360 m_3 <= x_3}} \{ 240 m_3 + f_4(x_3 - 360 m_3) \}$$

m_3 = 0,1,2

W/w_3	=	
		0
		180
360	1	360
		480
		660
360	2	720

STAGE 3

	m_3			Optimum	
X_3	0	1	2	$f_3(x_3)$	m_3^*
0	0			0	0
180	120			120	0
360	240	240		240	1
480	320	240		320	0
660	440	440		440	0,1
720	480	480	480	480	0,1, 2

W	w_2	W/w_2
866	480	1

$$f_2(x_2) = \max_{\substack{m_2 \\ 480 m_2 <= x_2}} \{ 320m_2 + f_3(x_2 - 480m_2) \}$$

m_2 = 0,1

W/w_2	=	0
480	1	480

STAGE 2

	m_2		Optimum	
X_2	0	1	$f_2(x_2)$	m_2^*
0	0		0	0
480	320	320	320	**0,1**

$X_2 = 480$ gives maxm $m_2 = 1$

$X_3 = X_2 - w_2 * m_2$

$X_3 = 480 - 480 * 1$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$

$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 4 is maximized when $m_2 = 1$, $m_3 = 0$, $m_4 = 0$, $m_5 = 0$

Thus, Belt 4 capacity is optimized with 1 Jumbo Aircraft

Alternative solutions for Belt 4 when D/a = 0.7 and in the Absence of NLA

$X_2 = 480$ gives $m_2 = 0$

Case 1. When $m_2 = 0$; $X_2 = 480$

$X_3 = X_2 - w_2\, m_2 = 480 - 480 \times 0 = 480$

$X_3 = 480$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 480$

$X_4 = X_3 - w_3\, m_3 = 480 - 360 \times 0 = 480$

$X_4 = 480$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 480$

$X_5 = X_4 - w_4\, m_4 = 480 - 300 \times 1 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_2	m_3	m_4	m_5
Optimum Solution	1	0	0	0
Alternative Solutions	0	0	1	1

Belt No 5.

W	w_5	W/w_5
1333	180	7

$$f_5(x_5) = \max_{m_5} \{120\, m_5 + 0\}$$

$$180\, m_5 <= X_5$$

m_5 = 0,1,2,3,4,5,6,7

W/w_5	=	
		0
		60
		120
180	1	180
		240
		300
180	2	360
		420
		480
180	3	540
		600
		660
180	4	720
		780
		840
180	5	900
		960
		1020
180	6	1080
		1200
180	7	1260

STAGE 5

	m_5								Optimum	
X_5	0	1	2	3	4	5	6	7	$f_5(x_5)$	m_5^*
0	0								0	0
60	0								0	0
120	0								0	0
180	0	120							120	1
240	0	120							120	1
300	0	120							120	1
360	0	120	240						240	2
420	0	120	240						240	2
480	0	120	240						240	2
540	0	120	240	360					360	3
600	0	120	240	360					360	3
660	0	120	240	360					360	3
720	0	120	240	360	480				480	4
780	0	120	240	360	480				480	4
840	0	120	240	360	480				480	4
900	0	120	240	360	480	600			600	5
960	0	120	240	360	480	600			600	5
1020	0	120	240	360	480	600			600	5
1080	0	120	240	360	480	600	720		720	6
1200	0	120	240	360	480	600	720		720	6
1260	0	120	240	360	480	600	720	840	840	7

W	w_4	W/w_4
1333	300	4

$$f_4(x_4) = \max_{m_4} \{200 m_4 + f_5(x_4 - 300 m_4)\}$$

$$300\, m_4 <= x_4$$

m_4 = 0,1,2,3,4

W/w_4	=	
		0
		120
		180
		240
300	1	300
		360
		480
300	2	600
		720
		840
300	3	900
		960
		1080
300	4	1200

STAGE 4

	m_4					Optimum	
X_4	0	1	2	3	4	$f_4(x_4)$	m_4^*
0	0					0	0
120	0					0	0
180	120					120	0
240	120					120	0
300	120	200				200	1
360	240	200				240	0
480	240	320				320	1
600	360	320	400			400	2
720	0	440	400			440	1
840	480	560	520			560	1
900	600	560	520	600		600	0,3
960	600	560	640	600		640	2
1080	720	680	640	720		720	0,3
1200	720	800	760	720	800	800	1,4

W	w_3	W/w_3
1333	360	3

$$f_3(x_3) = \max_{m_3} \{240\, m_3 + f_4(x_3 - 360\, m_3)\}$$

$$360\, m_3 <= x_3$$

m_3 = 0,1,2,3

W/w_3	=	0
		180
360	1	360
		480
360	2	720
		840
		960
360	3	1080

STAGE 3

	m_3				Optimum	
X_3	0	1	2	3	$f_3(x_3)$	m_3^*
0	0				0	0
180	120				120	0
360	240	240			240	1
480	320	240			320	0
720	440	480	480		480	2
840	560	560	480		560	0,1
960	640	640	600		640	0,1
1080	720	680	720	720	720	0,2,3

W	w_2	W/w_2
1333	480	2

$$f_2(x_2) = \max_{m_2} \{320 m_2 + f_3(x_2 - 480 m_2)\}$$

$$480\, m_2 <= x_2$$

m_2 = 0,1,2

W/w_2	=	0
480	1	480
480	2	960

STAGE 2

	m_2			Optimum	
X_2	0	1	2	$f_2(x_2)$	m_2^*
0	0			0	0
480	320	320		320	1
960	640	640	640	640	**0,1,2**

$X_2 = 960$ gives maxm $m_2 = 2$

$X_3 = X_2 - w_2 * m_2$
$X_3 = 960 - 480 * 2$

X3 = 0 gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$
$X_4 = 0 - 360 * 0$

X4 = 0 gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$
$X_5 = 0 - 300 * 0$

X5 = 0 gives maxm $m_5 = 0$

Utilization of Belt 5 is maximized when $m_2 = 2$, $m_3 = 0$, $m_4 = 0$, $m_5 = 0$
Thus, Belt 5 capacity is optimized with 2 Jumbo Aircraft

Alternative solutions for Belt 5 when D/a = 0.7 and in the Absence of NLA

$\mathbf{X_2 = 960}$ **gives** $\mathbf{m_2 = 0\ ;\ m_2 = 1}$

Case 1. When $m_2 = 0\ ;\ X_2 = 960$

$X_3 = X_2 - w_2\, m_2 = 960 - 480 \times 0 = 960$

$\mathbf{X_3 = 960}$ **gives** $\mathbf{m_3 = 0\ ;\ m_3 = 1}$

Case 1.1 When $m_3 = 0\ ;\ X_3 = 960$

$X_4 = X_3 - w_3\, m_3 = 960 - 360 \times 0 = 960$

$\mathbf{X_4 = 960}$ **gives** $\mathbf{m_4 = 2}$

When $m_4 = 2\ ;\ X_4 = 960$

$X_5 = X_4 - w_4\, m_4 = 960 - 300 \times 2 = 360$

$\mathbf{X_5 = 360}$ **gives** $\mathbf{m_5 = 2}$

Case 1.2. When $m_3 = 1\ ;\ X_3 = 960$

$X_4 = X_3 - w_3\, m_3 = 960 - 360 \times 1 = 600$

$\mathbf{X_4 = 600}$ **gives** $\mathbf{m_4 = 2}$

When $m_4 = 2\ ;\ X_4 = 600$

$X_5 = X_4 - w_4\, m_4 = 600 - 300 \times 2 = 360$

$\mathbf{X_5 = 0}$ **gives** $\mathbf{m_5 = 0}$

Case 2. When $m_2 = 1\ ;\ X_2 = 960$

$X_3 = X_2 - w_2\, m_2 = 1320 - 480 \times 1 = 480$

$\mathbf{X_3 = 480}$ **gives** $\mathbf{m_3 = 0}$

Case 2.1. When $m_3 = 0\ ;\ X_3 = 480$

$X_4 = X_3 - w_3\, m_3 = 480 - 360 \times 0 = 480$

$\mathbf{X_4 = 480}$ **gives** $\mathbf{m_4 = 1}$

When $m_4 = 1\ ;\ X_4 = 480$

$X_5 = X_4 - w_4\, m_4 = 480 - 300 \times 1 = 180$

$\mathbf{X_5 = 180}$ **gives** $\mathbf{m_5 = 1}$

	m_2	m_3	m_4	m_5
Optimum Solution	2	0	0	0
Alternative Solutions	0	0	2	2
	0	1	2	0
	1	0	1	1

In practical situations we can improve the D/a ratio towards unity (section 4.2). Thus, increasing the throughput or the effective capacity of the belts.

In this scenario number of m_i values will be high 1,2,3,......................(W/w_i) as well as need more x_i values for the computation making it complicated for a manual calculation. Thus, automation can be done on MS Excel to do large number of computation using many m_i and x_i values.

Eg. : Taking W = 3537 we get m_i = 19 and number of x_i =3537 implying 3537 x 19 cells in the worksheet.

A sample calculation is given in Appendix - C.

4.3 Sensitivity Analysis

As described earlier, at the end of Calculation, by increasing the D/a ratio towards unity it is possible to increase the throughput of the Baggage Belts (BHS infrastructure). By doing a sensitivity analysis it is possible to study the behaviour of the Maximum Return (Z) with the increase in D/a ratio. This is shown graphically in Graph 4-1.

Sensitivity Analysis has been done for D/a = 0.5, 0.6, 0.7

4.3.1 Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/ a = 0.5

Belts 1, 2 and 3

W	w_5	W / w_5
268	180	1

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$
$$180\, m_5 <= X_5$$

m_5 = 0,1

W / w_5 = 0, 60; 180 1 180

STAGE 5

	m_5		Optimum	
X_5	0	1	$f_5(x_5)$	m_5^*
0	0		0	0
60	0		0	0
180	0	120	120	**1**

$X_5 = 180$ gives maxm $m_5 = 1$

Utilization of Belt 1 is maximized when $m_5 = 1$

Thus, Belt 1 capacity is optimized with 1 (one) Small Aircraft

Belt 4

W	w_5	W / w_5
520	180	2

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$
$$180\, m_5 <= X_5$$

m_5 = 0,1,2

W / w_5 = 0, 60, 120; 180 1 180; 300; 180 2 360; 480

STAGE 5

	m_5			Optimum	
X_5	0	1	2	$f_5(x_5)$	m_5^*
0	0			0	0
60	0			0	0
120	0			0	0
180	0	120		120	1
300	0	120		120	1
360	0	120	240	240	2
480	0	120	240	240	2

W	w_4	W / w_4
520	300	1

$$f_4(x_4) = \max_{m_4} \{ 200 m_4 + f_5(x_4 - 300m_4) \}$$

$$300 m_4 <= x_4$$

m_4 = 0,1

W / w_4 = 0, 120, 180, 300, 360, 480

300 1 300

STAGE 4

	m_4		Optimum	
X_4	0	1	$f_4(x_4)$	m_4^*
0	0		0	0
120	0		0	0
180	120		120	0
300	120	200	200	1
360	240	200	240	0
480	240	320	320	1

W	w_3	W / w_3
520	360	1

$$f_3(x_3) = \max_{m_3} \{ 240 m_3 + f_4(x_3 - 360 m_3) \}$$

$$360 m_3 <= x_3$$

m_3 = 0,1

W / w_3 = 0, 180, 360, 480

360 1 360

STAGE 3

	m_3		Optimum	
X_3	0	1	$f_3(x_3)$	m_3^*
0	0		0	0
180	120		120	0
360	240	240	240	0, 1
480	320	240	320	0

W	w_2	W / w_2
520	480	1

$$f_2(x_2) = \max_{m_2} \{ 320m_2 + f_3(x_2 - 480m_2) \}$$

$$480 m_2 <= x_2$$

m_2 = 0,1

W / w_2 = 0, 480

480 1 480

STAGE 2

	m_2		Optimum	
X_2	0	1	$f_2(x_2)$	m_2^*
0	0		0	0
480	320	320	320	**0,1**

$X_2 = 480$ gives maxm $m_2 = 1$

$X_3 = X_2 - w_2 * m_2$

$X_3 = 480 - 480 * 1$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$

$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 4 is maximized when $m_2 = 1, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 4 capacity is optimized with 1 (one) Jumbo Aircraft

Alternative solutions for Belt 4 when D/a = 0.5

$X_2 = 480$ gives $m_2 = 0$

Case 1. When $m_2 = 0$; $X_2 = 480$

$X_3 = X_2 - w_2\, m_2 = 480 - 480 \times 0 = 480$

$X_3 = 480$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 480$

$X_4 = X_3 - w_3\, m_3 = 480 - 360 \times 0 = 480$

$X_4 = 480$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 480$

$X_5 = X_4 - w_4\, m_4 = 480 - 300 \times 1 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_2	m_3	m_4	m_5
Optimum Solution	1	0	0	0
Alternative Solutions	0	0	1	1

Belt 5

W	w_5	W / w_5
800	180	4

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$

$$180\, m_5 <= X_5$$

m_5 = 0,1,2,3,4

W / w_5 = 0

		0
		60
		120
180	1	180
		240
		300
180	2	360
		420
		480
180	3	540
		600
		660
180	4	720
		780

STAGE 5

	m_5					Optimum	
X_5	0	1	2	3	4	$f_5(x_5)$	m_5^*
0	0					0	0
60	0					0	0
120	0					0	0
180	0	120				120	1
240	0	120				120	1
300	0	120				120	1
360	0	120	240			240	2
420	0	120	240			240	2
480	0	120	240			240	2
540	0	120	240	360		360	3
600	0	120	240	360		360	3
660	0	120	240	360		360	3
720	0	120	240	360	480	480	4
780	0	120	240	360	480	480	4

W	w_4	W / w_4
800	300	2

$$f_4(x_4) = \max_{m_4} \{ 200\, m_4 + f_5(x_4 - 300 m_4) \}$$

$$300\, m_4 <= x_4$$

m_4 = 0,1,2

W / w_4 = 0

		0
		120
		180
		240
300	1	300
		360
		480
300	2	600
		660
		720

STAGE 4

	m_4			Optimum	
X_4	0	1	2	$f_4(x_4)$	m_4^*
0	0			0	0
120	0			0	0
180	120			120	0
240	120			120	0
300	120	200		200	1
360	240	200		240	0
480	240	320		320	1
600	360	320	400	400	2
660	360	440	400	440	1
720	0	440	400	440	1

W	w_3	W / w_3
800	360	2

$$f_3(x_3) = \max_{m_3} \{ 240\, m_3 + f_4(x_3 - 360\, m_3) \}$$

$$360\, m_3 <= x_3$$

m_3 = 0,1,2

STAGE 3

W / w_3 =			X_3	m_3 0	1	2	Optimum $f_3(x_3)$	m_3^*
		0	0	0			0	0
		180	180	120			120	0
360	1	360	360	240	240		240	1
		480	480	320	240		320	0
		660	660	440	440		440	0,1
360	2	720	720	440	480	480	480	1, 2

W	w_2	W / w_2
800	480	1

$$f_2(x_2) = \max_{m_2} \{ 320 m_2 + f_3(x_2 - 480 m_2) \}$$

$$480\, m_2 <= x_2$$

m_2 = 0,1

STAGE 2

W / w_2 =			X_2	m_2 0	1	Optimum $f_2(x_2)$	m_2^*
		0	0	0		0	0
480	1	480	480	320	320	320	1
		660	660	440	440	440	0,1

W	w_1	W / w_1
800	660	1

$$f_1(x_1) = \max_{m_1} \{ 440 m_1 + f_2(x_1 - 660 m_1) \}$$

$$660\, m_1 <= x_1$$

m_1 = 0,1

STAGE 1

W / w_1 =			X_1	m_1 0	1	2	Optimum $f_1(x_1)$	m_1^*
		0	0	0			0	0
660	1	660	660	440	440		440	**0,1**

$X_1 = 660$ gives maxm $m_1 = 1$

$X_2 = X_1 - w_1 * m_1$

$X_2 = 660 - 660 * 1 = 0$

$X_2 = 0$ gives maxm $m_2 = 0$

$X_3 = X_2 - w_2 * m_2$

$X_3 = 0 - 480 * 0$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$

$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 5 is maximized when $m_1 = 1, m_2 = 0, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 5 capacity is optimized with 1 (one) New Large Aircraft

Alternative solutions for Belt 5 when D/a = 0.5

$X_1 = 660$ gives $m_1 = 0$

Case 1. When $m_1 = 0$; $X_1 = 660$

$X_2 = X_1 - w_1 m_1 = 660 - 660 \times 0 = 660$

$X_2 = 660$ gives $m_2 = 0$; $m_2 = 1$

Case 1.1. When $m_2 = 0$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 0 = 660$

$X_3 = 660$ gives $m_3 = 0$; $m_3 = 1$

Case 1.1.1. When $m_3 = 0$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 0 = 660$

$X_4 = 660$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 660$

$X_5 = X_4 - w_4 m_4 = 660 - 300 \times 1 = 360$

$X_5 = 360$ gives $m_5 = 2$

Case 1.1.2. When $m_3 = 1$; $X_3 = 660$

$X_4 = X_3 - w_3\, m_3 = 660 - 360 \times 1 = 300$

$X_4 = 300$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 300$

$X_5 = X_4 - w_4\, m_4 = 300 - 300 \times 1 = 0$

$X_5 = 0$ gives $m_5 = 0$

Case 1.2. When $m_2 = 1$; $X_2 = 660$

$X_3 = X_2 - w_2\, m_2 = 660 - 480 \times 1 = 180$

$X_3 = 180$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 180$

$X_4 = X_3 - w_3\, m_3 = 180 - 360 \times 0 = 180$

$X_4 = 180$ gives $m_4 = 0$

When $m_4 = 0$; $X_4 = 180$

$X_5 = X_4 - w_4\, m_4 = 180 - 300 \times 0 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_1	m_2	m_3	m_4	m_5
Optimum Solution	**1**	0	0	0	0
Alternative Solutions	0	0	0	**1**	**2**
	0	0	**1**	**1**	0
	0	**1**	0	0	**1**

Total maximum return Z for the optimum Aircraft mix has been calculated using the equation

$Z = r_1 m_1 + r_2 m_2 + \ldots\ldots\ldots\ldots\ldots\ldots + r_5 m_5$

and the Z values are shown in Table A –10.

4.3.2 Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when $D/a = 0.6$

Belts 1, 2 and 3

W	w_5	W/w_5
335	180	1

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$

$$180\, m_5 <= X_5$$

$m_5 = 0,1$

STAGE 5

$W/w_5 = 0$, 60

180	1	180

300

	m_5		Optimum	
X_5	0	1	$f_5(x_5)$	m_5^*
0	0		0	0
60	0		0	0
180	0	120	120	1
300	0	120	120	1

W	w_4	W/w_4
335	300	1

$$f_4(x_4) = \max_{m_4} \{ 200\, m_4 + f_5(x_4 - 300m_4) \}$$

$$300\, m_4 <= x_4$$

$m_4 = 0,1$

STAGE 4

$W/w_4 = 0$

300	1	300

	m_4		Optimum	
X_4	0	1	$f_4(x_4)$	m_4^*
0	0		0	0
300	120	200	200	**1**

$X_4 = 300$ gives maxm $m_4 = 1$

$X_5 = X_4 - w_4 * m_4$
$X_5 = 300 - 300 * 1$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 1 is maximized when $m_4 = 1$, $m_5 = 0$

Thus, Belt 1 capacity is optimized with 1 (one) Medium Aircraft

Belt 4

W	w_5	W / w_5
650	180	3

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$
$$180\, m_5 <= X_5$$

m_5 = 0,1,2,3

W / w_5	=	0
		60
		120
180	1	180
		300
180	2	360
		480
180	3	540
		600

STAGE 5

	m_5				Optimum	
X_5	0	1	2	3	$f_5(x_5)$	m_5^*
0	0				0	0
60	0				0	0
120	0				0	0
180	0	120			120	1
300	0	120			120	1
360	0	120	240		240	2
480	0	120	240		240	2
540	0	120	240	360	360	3
600	0	120	240	360	360	3

W	w_4	W / w_4
650	300	2

$$f_4(x_4) = \max_{m_4} \{ 200\, m_4 + f_5(x_4 - 300m_4) \}$$
$$300\, m_4 <= x_4$$

m_4 = 0,1,2

W / w_4	=	0
		120
		180
300	1	300
		360
		480
300	2	600

STAGE 4

	m_4			Optimum	
X_4	0	1	2	$f_4(x_4)$	m_4^*
0	0			0	0
120	0			0	0
180	120			120	0
300	120	200		200	1
360	240	200		240	0
480	240	320		320	1
600	360	320	400	400	2

W	w_3	W / w_3
650	360	1

$$f_3(x_3) = \max_{m_3} \{ 240\, m_3 + f_4(x_3 - 360m_3) \}$$
$$360\, m_3 <= x_3$$

m_3 = 0,1

W / w_3	=	0
		180
360	1	360
		480

STAGE 3

	m_3		Optimum	
X_3	0	1	$f_3(x_3)$	m_3^*
0	0		0	0
180	120		120	0
360	240	240	240	0,1
480	320	240	320	0

W	w_2	W / w_2
650	480	1

$$f_2(x_2) = \max_{m_2} \{ 320m_2 + f_3(x_2 - 480m_2) \}$$

$$480\, m_2 <= x_2$$

$m_2 = 0,1$

$W / w_2 = 0$

480	1	480

STAGE 2

	m_2		Optimum	
X_2	0	1	$f_2(x_2)$	m_2^*
0	0		0	0
480	320	320	320	**0,1**

$X_2 = 480$ gives maxm $m_2 = 1$

$X_3 = X_2 - w_2 * m_2$

$X_3 = 480 - 480 * 1$

$X_3 = 0$ gives maxm $m_3 = 0$

$X_4 = X_3 - w_3 * m_3$

$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$X_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 4 is maximized when $m_2 = 1, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 4 capacity is optimized with 1 (one) Jumbo Aircraft

Alternative solutions for Belt 4 when D/a = 0.6

$X_2 = 480$ gives $m_2 = 0$

Case 1. When $m_2 = 0$; $X_2 = 480$

$X_3 = X_2 - w_2\, m_2 = 480 - 480 \times 0 = 480$

$X_3 = 480$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 480$

$X_4 = X_3 - w_3\, m_3 = 480 - 360 \times 0 = 480$

$X_4 = 480$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 480$

$X_5 = X_4 - w_4\, m_4 = 480 - 300 \times 1 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_2	m_3	m_4	m_5
Optimum Solution	1	0	0	0
Alternative Solutions	0	0	1	1

Belt 5

W	w_5	W / w_5
1000	180	5

$$f_5(x_5) = \max_{m_5} \{ 120\, m_5 + 0 \}$$

$$180\, m_5 <= X_5$$

m_5 = 0,1,2,3,4,5

W / w_5 =

		0
		60
		120
180	1	180
		240
		300
180	2	360
		420
		480
180	3	540
		600
		660
180	4	720
		780
		840
180	5	900
		960

STAGE 5

	m_5						Optimum	
X_5	0	1	2	3	4	5	$f_5(x_5)$	m_5^*
0	0						0	0
60	0						0	0
120	0						0	0
180	0	120					120	1
240	0	120					120	1
300	0	120					120	1
360	0	120	240				240	2
420	0	120	240				240	2
480	0	120	240				240	2
540	0	120	240	360			360	3
600	0	120	240	360			360	3
660	0	120	240	360			360	3
720	0	120	240	360	480		480	4
780	0	120	240	360	480		480	4
840	0	120	240	360	480		480	4
900	0	120	240	360	480	600	600	5
960	0	120	240	360	480	600	600	5

W	w_4	W / w_4
1000	300	3

$$f_4(x_4) = \max_{m_4} \{ 200 m_4 + f_5(x_4 - 300 m_4) \}$$

$$300 m_4 <= x_4$$

$m_4 = 0,1,2,3$

STAGE 4

$W / w_4 = 0, 120, 180, 240, 300, 360, 480, 600, 660, 720, 840, 900, 960$

						Optimum	
W/w	X_4	m_4 = 0	1	2	3	$f_4(x_4)$	m_4^*
	0	0				0	0
	120	0				0	0
	180	120				120	0
	240	120				120	0
300 1	300	120	200			200	1
	360	240	200			240	0
	480	240	320			320	1
300 2	600	360	320	400		400	2
	660	360	440	400		440	1
	720	0	440	400		440	1
	840	480	560	520		560	1
300 3	900	600	560	520	600	600	0,3
	960	600	560	640	600	640	2

W	w_3	W / w_3
1000	360	2

$$f_3(x_3) = \max_{m_3} \{ 240 m_3 + f_4(x_3 - 360 m_3) \}$$

$$360 m_3 <= x_3$$

$m_3 = 0,1,2$

STAGE 3

$W / w_3 = 0, 180, 360, 480, 660, 720, 840, 960$

					Optimum	
W/w	X_3	m_3 = 0	1	2	$f_3(x_3)$	m_3^*
	0	0			0	0
	180	120			120	0
360 1	360	240	240		240	1
	480	320	240		320	0
	660	440	440		440	0,1
360 2	720	440	480	480	480	2
	840	560	560	480	560	0,1
	960	640	640	600	640	0,1

W	w_2	W / w_2
1000	480	2

$$f_2(x_2) = \max_{m_2} \{ 320m_2 + f_3(x_2 - 480m_2) \}$$

$$480\, m_2 <= x_2$$

$m_2 = 0,1,2$

STAGE 2

	W / w_2	=	0
	480	1	480
			660
	480	2	960

	m_2			Optimum	
X_2	0	1	2	$f_2(x_2)$	m_2^*
0	0			0	0
480	320	320		320	1
660	440	440		440	0,1
960	640	640	640	640	0,1,2

W	w_1	W / w_1
1000	660	1

$$f_1(x_1) = \max_{m_1} \{440m_1 + f_2(x_1 - 660m_1) \}$$

$$660\, m_1 <= x_1$$

$m_1 = 0,1$

STAGE 1

	W / w_1	=	0
	660	1	660

	m_1		Optimum	
X_1	0	1	$f_1(x_1)$	m_1^*
0	0		0	0
660	440	440	440	**0,1**

$X_1 = 660$ gives maxm $m_1 = 1$

$x_2 = X_1 - w_1 * m_1$

$X_2 = 660 - 660 * 1 = 0$

$X_2 = 0$ gives maxm $m_2 = 0$

$x_3 = X_2 - w_2 * m_2$

$X_3 = 0 - 480 * 0$

$X_3 = 0$ gives maxm $m_3 = 0$

$x_4 = X_3 - w_3 * m_3$

$X_4 = 0 - 360 * 0$

$X_4 = 0$ gives maxm $m_4 = 0$

$x_5 = X_4 - w_4 * m_4$

$X_5 = 0 - 300 * 0$

$X_5 = 0$ gives maxm $m_5 = 0$

Utilization of Belt 5 is maximized when $m_1 = 1, m_2 = 0, m_3 = 0, m_4 = 0, m_5 = 0$

Thus, Belt 5 capacity is optimized with 1 (one) New Large Aircraft

Alternative Solutions for Belt 5 when D/a = 0.6

$X_1 = 660$ gives $m_1 = 0$

Case 1. When $m_1 = 0$; $X_1 = 660$

$X_2 = X_1 - w_1 m_1 = 660 - 660 \times 0 = 660$

$X_2 = 660$ gives $m_2 = 0$; $m_2 = 1$

Case 1.1. When $m_2 = 0$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 0 = 660$

$X_3 = 660$ gives $m_3 = 0$; $m_3 = 1$

Case 1.1.1. When $m_3 = 0$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 0 = 660$

$X_4 = 660$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 660$

$X_5 = X_4 - w_4 m_4 = 660 - 300 \times 1 = 360$

$X_5 = 360$ gives $m_5 = 2$

Case 1.1.2. When $m_3 = 1$; $X_3 = 660$

$X_4 = X_3 - w_3 m_3 = 660 - 360 \times 1 = 300$

$X_4 = 300$ gives $m_4 = 1$

When $m_4 = 1$; $X_4 = 300$

$X_5 = X_4 - w_4 m_4 = 300 - 300 \times 1 = 0$

$X_5 = 0$ gives $m_5 = 0$

Case 1.2. When $m_2 = 1$; $X_2 = 660$

$X_3 = X_2 - w_2 m_2 = 660 - 480 \times 1 = 180$

$X_3 = 180$ gives $m_3 = 0$

When $m_3 = 0$; $X_3 = 180$

$X_4 = X_3 - w_3 m_3 = 180 - 360 \times 0 = 180$

$X_4 = 180$ gives $m_4 = 0$

When $m_4 = 0$; $X_4 = 180$

$X_5 = X_4 - w_4 m_4 = 180 - 300 \times 0 = 180$

$X_5 = 180$ gives $m_5 = 1$

	m_1	m_2	m_3	m_4	m_5
Optimum Solution	1	0	0	0	0
Alternative Solutions	0	0	0	1	2
	0	0	1	1	0
	0	1	0	0	1

Total maximum return Z for the optimum Aircraft mix has been calculated using the equation

$$Z = r_1m_1 + r_2m_2 + \ldots\ldots\ldots\ldots + r_5m_5$$

and the Z values are shown in Table A –11.

Please refer the calculation under section 3.5.1. for Optimum Mix of Aircrafts for each Baggage Belt when (D/a) = 0.7

By performing similar calculations, when (D/a) = 0.4 and 0.8 corresponding values for Optimum Aircraft mix can be found.

5. Observations and Results

5.1 Comparison of systems used at other airports with those of BIA

The BHS used at BIA is not a fully automated system as in the case of major hubs and large airports described above. There is no immediate requirement to go for full automation as the total passenger flow and number of aircraft movements is within manageable range according to the data available (Table A-5) and the availability of abundant labour at competitive rates besides the government's policy to create more jobs. However, the present system of Baggage Reconciliation by means of Bar code reading using bar code scanners can be further improved by transforming to RFID Baggage Handling and Tracking system in time to come. As there is an IATA standard on this and as IATA is encouraging the use of RFID, the external environment will demand the implementation of this very soon.

5.2 Improving operational efficiency and throughput of the BHS at BIA

The mathematical model developed above gives the optimum use of Baggage Belts, when **(D/a)** = **0.7**, as follows.

Belt 1 capacity is optimized with 1 Large Aircraft (eg. B 747, B 777, A 340 etc.)

Belt 2 capacity is optimized with 1 Large Aircraft (eg. B 747, B 777, A 340 etc.)

Belt 3 capacity is optimized with 1 Large Aircraft (eg. B 747, B 777, A 340 etc.)

Belt 4 capacity is optimized with 1 New Large Aircraft (Airbus A 380)

Or

1 Medium Aircraft (B 767-300/ A 300-600 / A 310-300) and 2 Small Aircraft (A 320 / B 737-400)

Or

1 no. Large Aircraft (eg. B 747, B 777, A 340 etc.) and 1 no. Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300) and 1 no. Small Aircraft (A 320 / B 737-400)

Or

1 Jumbo Aircraft (B 747-400/ A 340 –600) and 1 Small Aircraft (A 320 / B 737-400)

Belt 5 capacity is optimized with 2 New Large Aircraft (Airbus A 380)

Or

2 Medium Aircraft (B 767-300/ A 300-600 / A 310-300) and 4 Small Aircraft (A 320 / B 737-400)

Or

1 Large Aircraft (eg. B 747, B 777, A 340 etc.) and 2 Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300) and 2 Small Aircraft (A 320 / B 737-400)

Or

2 Large Aircraft (eg. B 747, B 777, A 340 etc.) and 2 Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300)

Or

1 Jumbo (B 747-400/ A 340 –600) and 1 Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300) and 3 Small Aircraft (A 320 / B 737-400)

Or

1 Jumbo (B 747-400/ A 340 –600) and 1 Large Aircraft (eg. B 747, B 777, A 340 etc.) and 1 Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300) and 1 Small Aircraft (A 320 / B 737-400)

Or

2 Jumbo (B 747-400/ A 340 –600) and 1 Large Aircraft (eg. B 747, B 777, A 340 etc.)

Or

1 New Large Aircraft (Airbus A 380) and 1 Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300) and 2 Small Aircraft (A 320 / B 737-400)

Or

1 no. New Large Aircraft (Airbus A 380) and 1 no. Large Aircraft (eg. B 747, B 777, A 340 etc.) and 1 no. Medium Aircraft (B 767 –300/ A 300 –600/ A 310 -300)

Or

1 New Large Aircraft (Airbus A 380) and 1 Jumbo (B 747-400/ A 340 –600) and 1 Small Aircraft (A 320 / B 737-400)

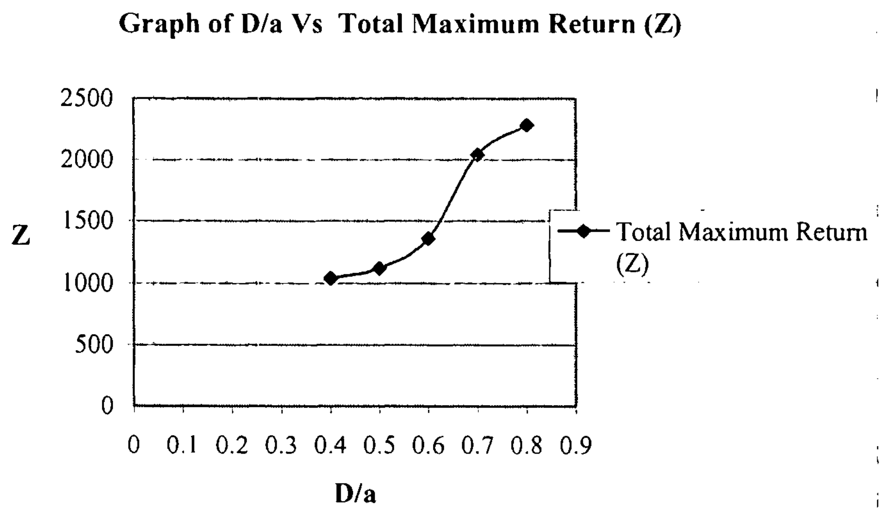
From equation (1) it is clear that the Belt capacity can be increased if unloading rate is increased. Equal Loading and unloading rates will make the belt capacities infinite which is unrealistic. Hence, higher value of unloading rate is desirable and can be achieved by

- Increasing the accessibility to belts by re sizing the baggage re-claim area depending on the passenger capacity.
- Reducing the passenger walking distance after the immigration. and other formalities.
- Employing baggage belt attendants to unload the baggage, which are remaining on belt for long time without claiming.

5.2.1 Outcome of Sensitivity Analysis when D/a = 0.4, 0.5, 0.6, 0.7 and 0.8

Refer Table A – 10, A – 11 and A – 12.

D/a	Total Maximum Return (Z)
0.4	1040
0.5	1120
0.6	1360
0.7	2040
0.8	2280



Graph 4-1: D/a vs. Total Return (Z)

5.3 Minimizing the number of lost / mishandled baggage.

The lost and mishandled baggage numbers at BIA are within the allowable limits and as given in the table above deliver a high LOS which is commendable when compared to other Airlines/Airports.

This status can be further improved or retained by

- Improving / ensuring high Print quality of bag tags.
- Reducing Bag tagging errors at check-in
- Minimizing/ eliminating possible tearing of bag tags.
- Avoiding late acceptance of bags.
- Eliminating/reducing mis-sorting, mis-reading or mis-loading.
- Avoiding the overlooking and not loading the bag.
- Improving quality and accuracy in Baggage transfers resulting in late arriving connections.

5.4 The impact of Airbus A380 on Baggage Handling operations at BIA

As shown above the A 380 demand can be met with the present BHS, as far as Arrival Baggage re-claim belts are concerned. However, this is going to be dependent on the peak aircraft mix.

6. Analysis & Discussion

The baggage handling system used at BIA is a human intervened one and not a fully automated one. There is a Bar code scanning system for reconciliation of baggage but the rest of the job is manual by the ground handling staff using the required equipment / vehicles.
Fully automated Baggage handling system cannot be justified for BIA at present or in time to come as there is enough labour at competitively low rates and when considered the size of the airport and passenger volume.

Besides the lessons learnt from the automation of 'Denver International Airport' has to taken in to account in such a move as it is not economical / justifiable to have one or more back-up systems to a fully automated system as in Denver

It is recommended to replace the present Bar code scanning system with the RFID system by 2010 (when passenger volume reaches 7 million) so that a higher level of service can be assured to the passengers while eliminating the drawbacks of the present system. This will be justified by the demand for accurate reading of baggage tags so as to minimize the number of mishandled baggage with the increase in volume of baggage handled at BIA.

The Table A-4 shows that the Transfer passengers accounted for 14.96 % in 2004 and it was increasing at a rate of 81.8 % in the year 2004 over the previous year.

However, there is a serious shortcoming in the BIA Baggage Handling Infrastructure as there is no baggage carousel exclusively for unloading transfer baggage and to scan them then and there before loading and despatching them to respective aircrafts. At the moment this process is carried out at the Arrival Baggage unloading area and the process seem to be primitive compared to other airports. In most of the other airports such a carousel is available exclusively for such purpose which results in efficient and effective system / process and higher level of service.

In order to improve the existing system & for optimum utilization of existing set of baggage belts the results obtained in the mathematical modelling of the system can be made use of.

According to the results, it is possible to make use of the existing infrastructure (baggage belt capacities) to cater for the present peak demand as the present peak demand is for 3 large aircrafts and 6 small aircrafts. As Belts 1,2,3 each can be loaded with baggage of 2 nos. small aircrafts and NLAs are not operating at present the above demand can be met/ accommodated.

But the demand in the year 2015 cannot be met for none of the cases low, medium and high shown in Table A -9 .Thus the BHS capacity to be expanded to suit the demand in 2015 may it be low case, medium case or high case.

As discussed in this report, mishandled baggage results in incurring heavy losses to Airlines according to the figures given there.

However, the service levels are acceptable as the 'number of lost baggage per 1000 passengers' is below the industry defined values.

The results of the study shows that it is possible to cope up with the demand created by the operation of Airbus A 380 to Colombo which is expected to start operation in the year 2008 provided that the total peak hour aircraft mix is not more than 6 aircrafts while the number of A 380 s operated does not exceed 3 nos.

Thus, it is possible to use Baggage Belts No.4 and/or Belt No. 5 to meet A 380 demand as above.

However if the number of A 380s operated going to increase, then the number of Belts to be increased by the required number.

Maximum Aircraft Mix for (D/a) = 0.7

Belt 1	**:**	**1 Large Aircraft**
Belt 2	**:**	**1 Large Aircraft**
Belt 3	**:**	**1 Large Aircraft**
Belt 4	**:**	**1 Medium Aircraft and 2 Small Aircraft**
Or	**:**	**1 Large Aircraft and 1 Medium Aircraft. and 1 Small Aircraft**
Belt 5	**:**	**2 Medium Aircraft and 4 Small Aircraft**

Maximum Aircraft Mix (D/a = 0.7)		New Large Aircraft	Jumbo (Jet) Aircraft	Large Aircraft	Medium Aircraft	Small Aircraft	Total Aircraft	Maximum Return (Z)
Belt 1		-	-	1	-	-	1	240
Belt 2		-	-	1	-	-	1	240
Belt 3		-	-	1	-	-	1	240
Belt 4	Case 1	-	-	-	1	2	3	440
	Case 2	-	-	1	1	1	3	560
Belt 5		-	-	-	2	4	6	880
Total (with Case 1)		-	-	3	3	6	12	2040
Total (with Case 2)		-	-	4	3	5	12	2160

The maximum Aircraft mix shown in the above Table can be compared with the Table A -9 which shows the present peak hour aircraft mix and the peak hour demand forecast for the year 2015 for each Low, Medium and High case and the following conclusions can be made.

1. The Demand for Baggage Belts created by the present peak hour aircraft mix can be met with existing number of Baggage Belts, if utilized optimally as found and described above.

2. The peak hour demand in 2015 cannot be met ,for any of the three cases (Low, Medium and High), with the existing number and / or capacities of Baggage Belts. Therefore, to cater for the demand in 2015, either the Belt capacities have to be augmented or new Belts designed to cater for New Large Aircrafts (A 380) and Jumbo Jet Aircrafts will have to be introduced.

2. The Optimum Aircraft mix when D/a = 0.7 and **without the presence of NLA** (Airbus A 380) is as follows.

Maximum Aircraft Mix (D/a = 0.7)	New Large Aircraft	Jumbo (Jet) Aircraft	Large Aircraft	Medium Aircraft	Small Aircraft	Total Aircraft	Maximum Return (Z)
Belt 1		-	1	-	-	1	240
Belt 2		-	1	-	-	1	240
Belt 3		-	1	-	-	1	240
Belt 4		-	-	1	1	2	320
Belt 5		-	-	2	2	4	640
Total		-	3	3	3	9	1660

6.1 Qualitative Analysis

6.1.1 The criteria used at BIA for allocating Baggage Belts

At the moment no criteria is available, to be followed when assigning Belts for various aircrafts, with the Ground Handling Agent at BIA. The practise is to allocate or assign the available Belt which is closest to the Customs area to enhance fast clearing at the customs desks and fast movement of arriving passengers.

However, study done in this respect & the results/data given in the Tables A-10, A-11 and A-12 shows that whenever feasible, Belt 4 is allocated for Jumbo jet Aircrafts such as B 747. But it is to be mentioned that there is no hard and fast rule on this or the assignment of Baggage Belts.

Therefore, the outcome of this study on Optimum utilisation of available Baggage Belts will be very useful to both the Airport operator, Airport and Aviation Services (Sri Lanka) Ltd. and the Ground Handling Agent at BIA: Sri Lankan Airlines Ltd.

A record of Belts allocated for various types of Aircrafts arrived on three different dates / time is shown in Tables A-10, A-11 and A-12.

6.1.2 Comparison of the current practise of allocating baggage Belts and the Proposed / recommended method.

Eg. Arrival Aircraft mix on Tuesday 3 rd January 2006 between 10.21 a.m. and 11.28 a.m. is as follows.

Small 2
Large 2
Jumbo 1

Belt No.	Actual Belt Assignment			Proposed Belt Assignment		
	Small	Large	Jumbo	Small	Large	Jumbo
1	1	-	-	-	1	-
2	1	1	-	-	1	-
3	-	1	-	1	-	-
4	-	-	1	1	-	1

As per the results obtained after the study (calculation), When (D/a) = 0.7, Belts 1,2 and 3 each can be assigned 1 Large Aircraft while Belt 4 can be assigned 1 Jumbo and 1 small aircraft.

But, when allocating belts for the aircrafts mixed, the user (Ground Handling Agent) has assigned 1 small aircraft for Belt 1 and 1 small aircraft and 1 large aircraft for Belt 2, which does not optimize the capacity (underutilized) in the case of Belt 1 and leads to low Level of Service (LOS) in the case of Belt 2 as it is over utilized. In the case of Belt 4, the actual assignment is the same as the proposed and hence acceptable.

Therefore, by following the 'Proposed Belt Assignment Strategy' utilization of Baggage Belts can be optimized and the Belt 5 can be used /reserved for a higher capacity aircraft such as NLA or any other combination as described in the report.

7. Conclusion

The main objective of the Research was to find out ways of increasing efficiency and throughput by optimum utilization of Baggage Belts. The outcome of the Research can be used to manage and utilize the existing Baggage Handling System Infrastructure more efficiently and effectively while maximizing the Return.
The results will be highly useful for the Baggage Belt Operator, who is the Ground Handling Agent at BIA: M/s. Sri Lankan Airlines, in developing criteria on the effective utilization of available resources, especially because a similar criteria is not available at present.

Further, the results of both the Quantitative Analysis and the Qualitative Analysis gives a clear picture on the present demand and the available capacity as well as the medium term (2015) demand and the capacity requirements to meet that demand.

The study gives a detailed comparison of Baggage Handling systems and technologies used at other leading airports. It also gives the recommendations for minimizing of mishandled / lost baggage and the ways of meeting the expected demand created by the operation of NLA : Airbus A 380 and the ways of mitigating its impacts on the BHS at BIA.

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Appendix – A

Month	Passenger Movements			Transfer Pax	% Transfer Pax
	Uplift	Discharge	Total		
January	164,563	147,286	311,849	53,637	17.2
February	140,586	134,668	275,254	49,026	17.8
March	167,487	170,189	337,676	61,247	18.1
April	176,266	169,886	346,152	63,441	18.3
May	178,375	174,898	353,273	78,502	22.2
June	174,104	186,901	361,005	83,639	23.2
July	180,832	191,220	372,052	78,511	21.1
August	231,832	198,258	430,090	81,086	18.9
September	191,441	177,995	369,436	71,709	19.4
October	202,440	186,382	388,822	69,101	17.8
November	199,213	192,556	391,769	72,600	18.5
December	193,649	194,683	388,332	82,134	21.1
Total	**2,200,788**	**2,124,922**	**4,325,710**	**844,633**	**19.5**

Table A – 1: Passenger Movements - Year 2005 (Source: Data Base of Airport and Aviation Services Ltd)

Year	Passengers	Annual Growth	Cargo (tons)	Annual Growth	Aircraft Movements	Annual Growth
1990	1,471,711	-	39,830	-	17,864	-
1991	1,521,472	3.38%	44,600	11.98%	18,110	1.38%
1992	1,797,333	18.13%	50,092	12.31%	19,772	9.18%
1993	1,893,819	5.37%	56,927	13.64%	20,481	3.59%
1994	2,156,137	13.85%	70,171	23.26%	20,960	2.34%
1995	2,234,962	3.66%	77,639	10.64%	19,445	-6.99%
1996	2,148,578	-3.87%	85,719	10.41%	20,722	6.29%
1997	2,319,272	7.94%	97,436	13.67%	22,568	8.91%
1998	2,356,836	1.62%	94,364	-3.15%	24,055	6.59%
1999	2,648,780	12.39%	103,865	10.07%	27,140	12.82%
2000	2,880,387	8.74%	128,312	23.54%	32,123	18.36%
2001	2,628,043	-8.76%	101,547	-20.86%	26,363	-17.93%
2002	2,766,164	5.26%	112,274	10.56%	25,276	-4.12%
2003	3,232,762	16.87%	125,665	11.93%	27,937	10.53%
2004	4,069,721	25.89%	145,674	15.92%	35,161	25.86%
Average growth		7.89%		10.28%		5.49%
First half in 2005	1,980,189	5.50%	78,416	17.28%	20,276	23.98%

Table A – 2: Air Traffic Record at Bandaranaike International Airport (Source: Data Base of Airport and Aviation Services Ltd)

Month	Aircraft Movements				Cargo (MT)			Mail (MT)		
	Sch.	Non-Sch.	Others	Total	Uplift	Discharge	Total	Uplift	Discharge	Total
January	2,537	1,149	941	4,627	7,188	7,409	14,597	36	64	100
February	2,213	389	588	3,190	7,221	4,899	12,120	32	57	89
March	2,441	267	498	3,206	8,806	5,278	14,084	38	64	102
April	2,287	248	398	2,933	6,942	4,906	11,848	41	58	99
May	2,415	240	620	3,275	7,374	4,955	12,329	43	56	99
June	2,393	225	427	3,045	7,831	5,029	12,860	38	50	88
July	2,511	197	477	3,185	9,399	5,385	14,784	42	62	104
August	2,542	189	806	3,537	7,970	5,251	13,221	39	62	101
September	2,418	169	853	3,440	7,727	5,146	12,873	38	63	101
October	2,461	236	688	3,385	8,505	5,655	14,160	42	66	108
November	2,429	216	886	3,531	7,633	4,974	12,607	35	65	100
December	Not Available	Not Available	Not Available	Not Available	9,106	5,533	14,639	54	89	143
Total	**26,647**	**3,525**	**7182**	**37,354**	**95,702**	**64,420**	**160,600**	**478**	**756**	**1,234**

Table A – 3: Monthly Statistics – Aircrafts, Cargo and Mail -Year 2005 (Source: Data Base of Airport and Aviation Services Ltd)

Year /Month	1998	1999	2000	2001	2002	2003	2004	2005
January	-	22,445	22,533	37,392	19,787	29,958	47,589	53,637
February	-	16,783	22,586	34,714	20,511	24,722	38,989	49,026
March	14,695	18,192	24,009	34,564	22,204	19,936	40,444	61,247
April	15,087	19,129	19,587	32,402	17,863	18,430	43,895	63,441
May	15,437	19,545	25,794	33,429	23,294	20,764	48,442	78,502
June	16,450	19,453	28,497	35,342	19,162	20,706	51,781	83,639
July	18,186	19,323	35,249	32,839	19,836	26,698	57,663	78,511
August	14,805	19,236	36,580	20,074	20,331	25,883	62,430	81,086
September	15,692	19,582	33,159	17,295	18,279	35,383	52,885	71,709
October	14,426	18,486	31,716	15,131	24,481	34,230	51,157	69,101
November	14,675	20,021	31,766	16,888	25,286	35,226	54,606	-
December	15,808	21,573	31,064	19,591	29,907	42,077	59,065	-
Total Transfer / Transit	**115,261**	**233,768**	**342,540**	**329,661**	**260,941**	**334,013**	**608,946**	**689,899**
Annual Growth Rate	-	**50.6%**	**46.5%**	**-3.8%**	**-20.8%**	**28.0%**	**81.8%**	
Total Passengers	**2,356,836**	**2,648,780**	**2,880,387**	**2,628,043**	**2,766,164**	**3,232,762**	**4,069,721**	
% Transfer of Total Passengers	**4.89**	**8.83**	**11.89**	**12.54**	**9.43**	**10.33**	**14.96**	

Table A – 4: Total Transfer, Transit Passengers at BIA (From 1998 ~ 2005) (Source: Data Base of Airport and Aviation Services Ltd)

Year	Passenger Forecast				Cargo Forecast				Aircraft Forecast			
	Prob. Growth		High Growth		Prob. Growth		High Growth		Prob. Growth		High Growth	
	Annual Growth Rate	Pax. Moveme nt (mil)	Annual Growth Rate	Pax. Moveme nt (mil)	Annual Growth Rate	Cargo Movement (tons)	Annual Growth Rate	Cargo Moveme nt (tons)	Annual Growth Rate	Acft. Moveme nt	Annual Growth Rate	Acft. Moveme nt
2004 (actual)	25.9%	4.07	25.9%	4.07	15.9%	145,674	15.9%	145,674	0.0%	35,161	0.0%	35,161
2005	7.9%	4.39	9.5%	4.46	12.1%	161,698	14.3%	166,505	6.1%	37,306	7.9%	37,939
2006	7.5%	4.72	9.1%	4.86	11.0%	179,485	13.2%	188,484	5.5%	39,358	7.3%	40,708
2007	7.5%	5.07	9.1%	5.30	11.0%	199,228	13.2%	213,364	5.5%	41,522	7.3%	43,680
2008	7.5%	5.46	9.1%	5.79	11.0%	221,143	13.2%	241,528	5.5%	43,806	7.3%	46,869
2009	7.5%	5.86	9.1%	6.31	11.0%	245,469	13.2%	273,410	5.5%	46,215	7.3%	50,290
2010	7.5%	6.30	9.1%	6.89	11.0%	272,471	13.2%	309,500	5.5%	48,757	7.3%	53,961
2011	7.2%	6.76	8.7%	7.49	11.0%	302,443	13.2%	350,354	5.2%	51,293	6.9%	57,684
2012	7.2%	7.24	8.7%	8.14	11.0%	335,711	13.2%	396,601	5.2%	53,960	6.9%	61,665
2013	7.2%	7.77	8.7%	8.85	11.0%	372,639	13.2%	448,952	5.2%	56,766	6.9%	65,920
2014	7.2%	8.33	8.7%	9.62	11.0%	413,630	13.2%	508,213	5.2%	59,718	6.9%	70,468
2015	7.0%	8.91	8.7%	10.45	11.0%	459,129	13.2%	575,298	5.2%	62,823	6.9%	75,330
2016	7.0%	9.53	8.3%	11.32	10.0%	505,042	12.3%	646,059	5.0%	65,964	6.5%	80,227
2017	7.0%	10.20	8.3%	12.26	10.0%	555,546	12.3%	725,524	5.0%	69,262	6.5%	85,442
2018	7.0%	10.91	8.3%	13.28	10.0%	611,101	12.3%	814,764	5.0%	72,725	6.5%	90,995
2019	7.0%	11.68	8.3%	14.38	10.0%	672,211	12.3%	914,980	5.0%	76,362	6.5%	96,910
2020	7.0%	12.49	8.3%	15.57	10.0%	739,432	12.3%	1,027,522	5.0%	80,180	6.5%	103,209

Table A – 5: Passenger, Cargo and Aircraft Movement Forecast (Source: Data Base of Airport and Aviation Services Ltd)

Month	No. of Bags Mishandled	No. of Bags Uplifted.
Sep. 2004	183	118,218
Oct. 2004	153	102,343
Nov. 2004	198	104,554
Dec. 2004	332	122,649
Jan. 2005	293	116,871
Feb. 2005	218	101,296
Mar. 2005	227	121,534
Apr. 2005	167	131,136
May 2005	146	121,416
Jun. 2005	301	137,036
Jul. 2005	451	138,843
Aug. 2005	538	180,818
Average	267	124,726

Table A – 6: Mishandled Bags – Sri Lankan Airlines Flights (Sep.2004 - Aug. 2005)
(Source: Sri Lankan Airline Ltd)

Belt No.	Length (m)	Capacity (kg/m)	Total Capacity (kg)	No. of Equivalent 25 kg Baggage	Actual Capacity
1	67	50	3350	134	446
2	67	50	3350	134	446
3	67	50	3350	134	446
4	65	100	6500	260	866
5	100	100	10000	400	1333

Table A – 7: Baggage Belt Capacity (Source: Airport and Aviation Services Ltd)

Aircraft		Seating Capacity (Nos)	Load Factor	Pax. Capacity (Nos)	No of Baggage *
Definition	Seats				
New Large	A380	550	0.8	440	660
Jumbo	B747 - 400	400	0.8	320	480
	A340 - 600	400	0.8	320	480
Large	B747 - 200	300	0.8	240	360
	B777 - 300ER	300	0.8	240	360
	B777 - 200LR	300	0.8	240	360
	A340 - 300	300	0.8	240	360
	A330 - 300	300	0.8	240	360
Medium	B767 - 300	250	0.8	200	300
	A300 - 600	250	0.8	200	300
	A310 - 300	250	0.8	200	300
Small	A320	150	0.8	120	180
	B737 - 400	150	0.8	120	180

*Assume Bags/Pax = 1.5 [current industry std.]

Table A – 8: Aircraft Seating and Baggage Capacity (Source: Airport and Aviation Services Ltd)

Aircraft	Seating Capacity (Nos)	Peak Hour Traffic Demand (Present)	Peak HourTraffic Demand Forecast (2015)		
			Low Case	Medium Case	High Case
New Large	550	-	1	1	1
Jumbo	400	-	1	2	2
Large	300	3	3	4	6
Medium	250	-	4	3	3
Small	150	6	2	2	1
Total		**9**	**11**	**12**	**13**

Table A – 9: Forecast of Passenger Aircraft Traffic Demand (Source: (BIADP –Phase II Stage II Feasibility Study Report)

Belt No.	Optimum / Alternative Solution	m_1	m_2	m_3	m_4	m_5	Maximum Mix	Total Maximum Return (Z)
1	Optimum	-	-	-	-	1	1	120
2	Optimum	-	-	-	-	1	1	120
3	Optimum	-	-	-	-	1	1	120
4	Optimum	-	1	0	0	0	-	-
	Alternative	-	0	0	1	1	2	320
5	Optimum	1	0	0	0	0	-	-
	Alternative	0	0	0	1	2	3	440
		0	0	1	1	0	-	-
		0	1	0	0	1	-	-
Total Z								1120

Table A – 10: Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/a = 0.5

Belt No.	Optimum /Alternative Solution	m_1	m_2	m_3	m_4	m_5	Maximum Mix	Total Maximum Return (Z)
1	Optimum	-	-	-	1	0	1	200
2	Optimum	-	-	-	1	0	1	200
3	Optimum	-	-	-	1	0	1	200
4	Optimum	-	1	0	0	0	-	-
	Alternative	-	0	0	1	1	2	320
5	Optimum	1	0	0	0	0	-	-
	Alternative	0	0	0	1	2	3	440
		0	0	1	1	0	-	-
		0	1	0	0	1	-	-
Total Z								1360

Table A – 11: Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/a = 0.6

Belt No.	Optimum / Alternative Solution	m_1	m_2	m_3	m_4	m_5	Maximum Mix	Total Maximum Return (Z)
1	Optimum	-	-	1	0	0	1	240
2	Optimum	-	-	1	0	0	1	240
3	Optimum	-	-	1	0	0	1	240
4	Optimum	1	0	0	0	0	-	-
	Alternative	0	0	0	1	2	3	440
		0	0	1	1	1	-	-
		0	1	0	0	1	-	-
5	Optimum	2	0	0	0	0	-	-
	Alternative	0	0	0	2	4	6	880
		0	0	1	2	2	-	-
		0	0	2	2	0	-	-
		0	1	0	1	3	-	-
		0	1	1	1	1	-	-
		0	2	1	0	0	-	-
		1	0	0	1	2	-	-
		1	0	1	1	0	-	-
		1	1	0	0	1	-	-
Total Z								**2040**

Table A – 12: Optimum Mix of Aircrafts and the Maximum Return for each Baggage Belt when D/a = 0.7

Flight No.	Landed Time	Aircraft Type	Aircraft Category	Baggage Belt Assigned
UL 132	1021	A 320	Small	1
SV 784	1034	B 747	Jumbo	4
UL 316	1034	A 330	Large	3
UL 166	1125	A 320	Small	2
UL 162	1128	A 340	Large	2
UL 102	1143	A 320	Small	4
UL 170	1146	A 320	Small	2
EK 558	1201	A 330	Large	3
UL 172	1210	A 320	Small	2
UL 122	1222	A 330	Large	1

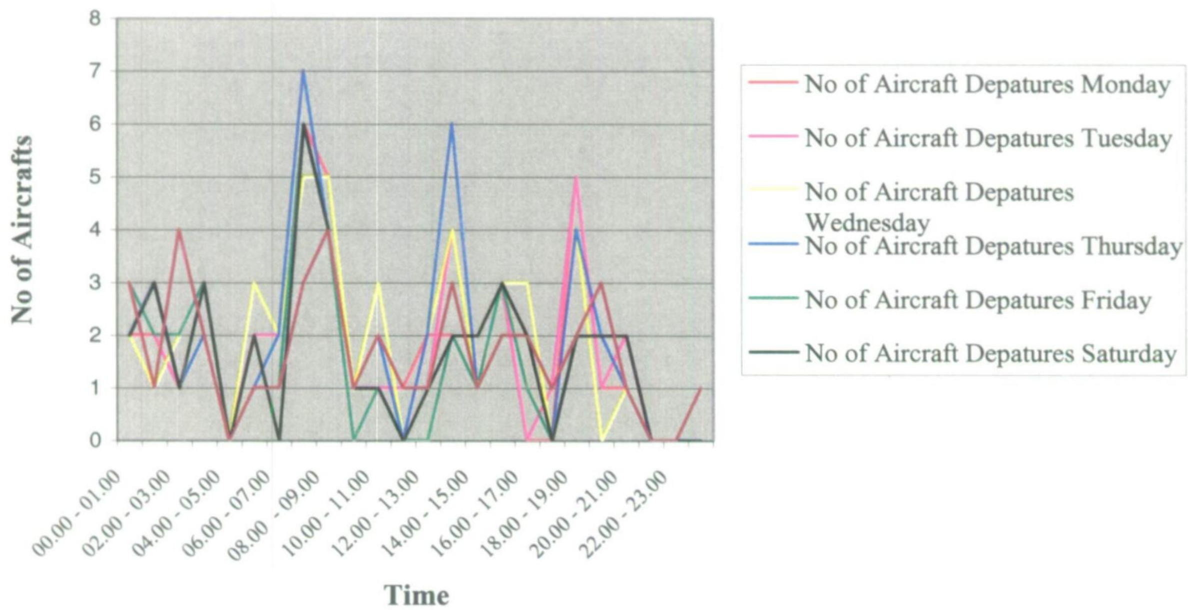
Table A – 13: Record of Belt Assignment for Passenger Aircrafts arrived on Tuesday 3rd January 2006

Flight No.	Landed Time	Aircraft Type	Aircraft Category	Baggage Belt Assigned
SQ 505	0420	A 320	Small	1
UL 228	0511	A 330	Large	3
UL 106	0516	A 320	Small	1
OK 188	0535	A 310	Medium	4
UL 569	0538	A 340	Large	2
RJ 194	0545	A 310	Medium	1
UL 216	0603	A 330	Large	3
KV 361	0617	A 300	Medium	2
UL 144	0651	A 320	Small	1
QR 300	0739	A 330	Large	3
EY 201	0743	A 330	Large	4

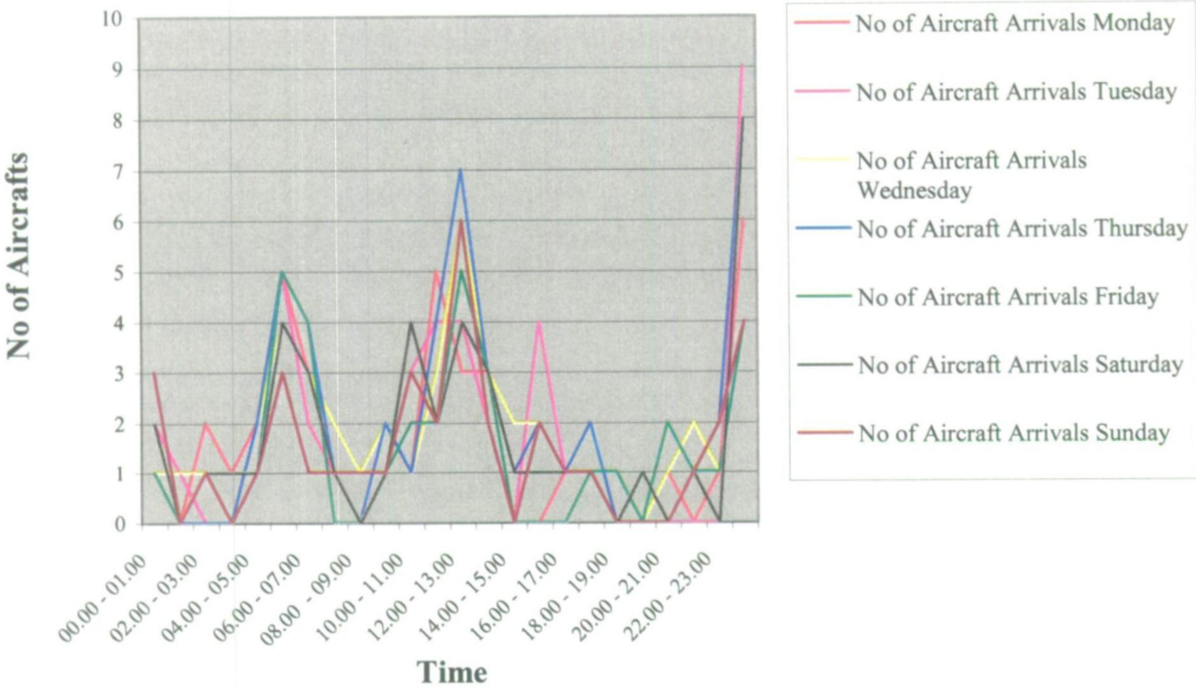
Table A – 14: Record of Belt Assignment for Passenger Aircrafts arrived on Saturday 7th January 2006

Flight No.	Landed Time	Aircraft Type	Aircraft Category	Baggage Belt Assigned
SQ 505	0412	A 320	Small	4
UL 230	0426	A 330	Large	3
UL 506	0432	A 340	Large	2
UL 567	0452	A 330	Large	1
UL 106	0508	A 320	Small	4
UL 228	0526	A 330	Large	2
UL 216	0607	A 330	Large	3
UL 284	0609	A 340	Large	1
UL 144	0633	A 320	Small	4
KU 361	0657	A 300	Medium	2
EY 201	0728	A 330	Large	4
QR 300	0805	A 330	Large	3

Table A – 15: Record of Belt Assignment for Passenger Aircrafts arrived on Monday 9th January 2006



Graph A – 16: No. of Aircrafts departures – (Monday – Sunday)



Graph A – 17: No. of Aircrafts Arrivals – (Monday – Sunday)

Appendix – B

1. Baggage Handling – Departure

Fig B1-1: Departure Baggage Check – in Counter

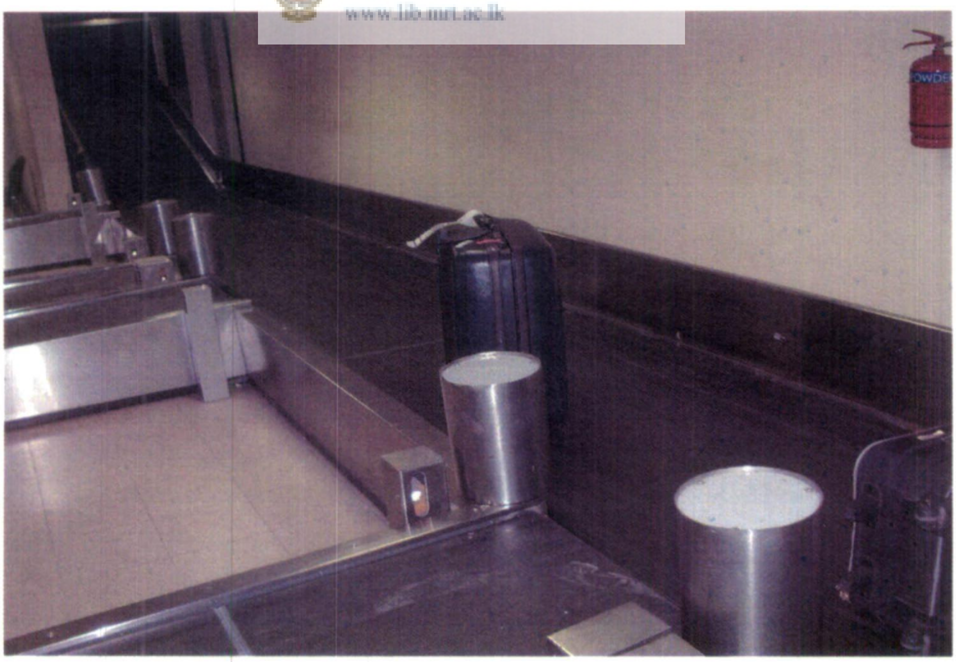


Fig B1-2: Departure Baggage Belt

Fig B1-3: Departure Baggage Carousel

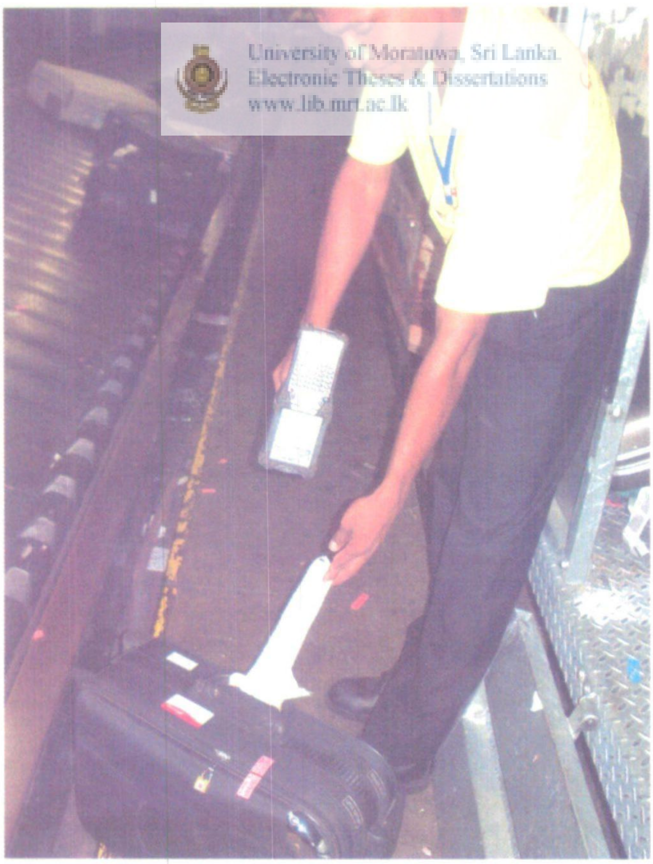


Fig B1-4: A Baggage scanned by an Airline employee

Fig B1-5: Loading baggage to ULD

Fig B1-6: Loaded Baggage Trolley ready for dispatching to the aircraft

2. Baggage Handling – Arrival

Fig B2-1: Aircraft Baggage Hole & Equipment used for loading/unloading

Fig B2-2: Unloading Baggage from Aircraft

Fig B2-3: ULD unloaded to a baggage dolly for dispatching to the Arrival Baggage Carousel

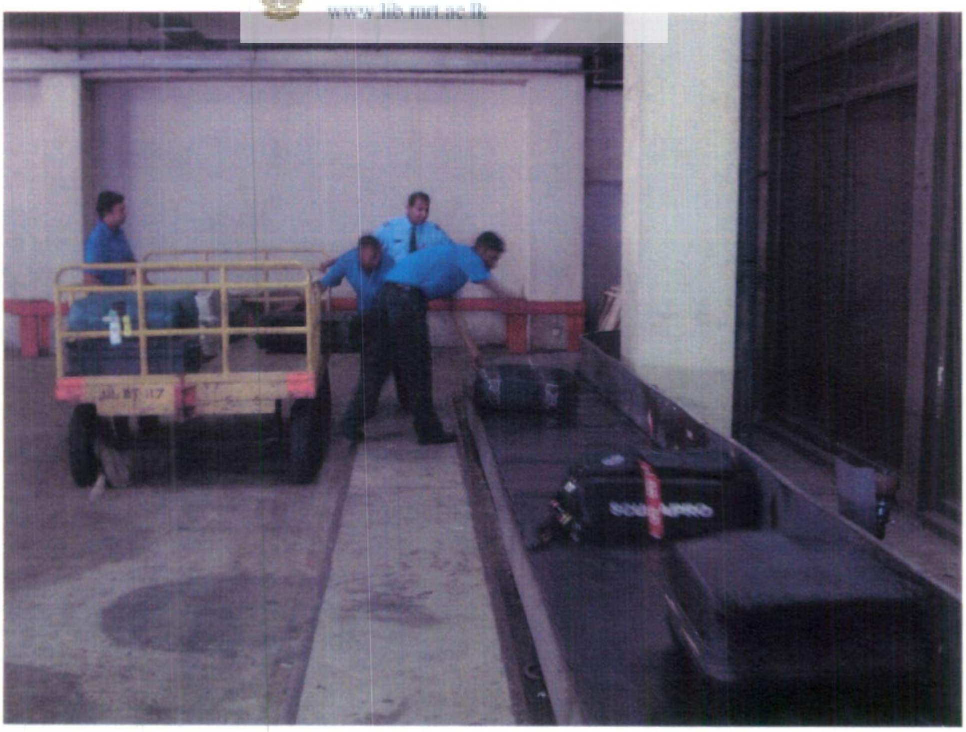


Fig B2-4: Unloading the Baggage to Baggage Belts (arrival)

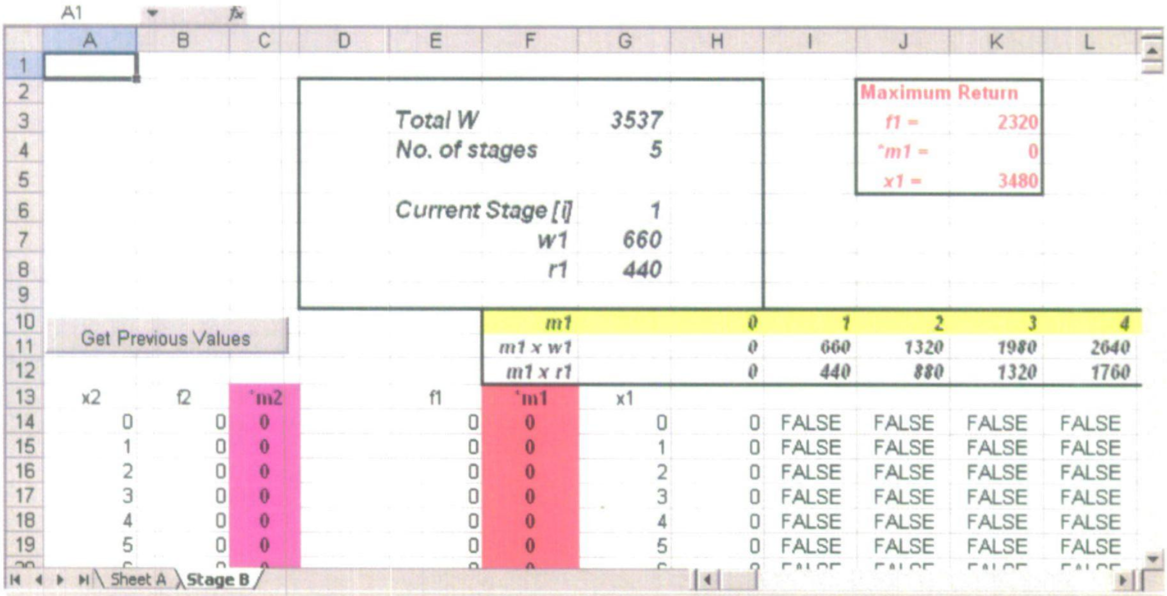
Fig B2-5: Baggage re-claimed by passengers.

Fig B2-6: Arrival Baggage re-claims Belt (Carousel).

Computer Based Calculation system using *MS EXCEL*

Sample Calculation

X1=3480
M1=0
X2=x1-w1m1=3480-0=3480

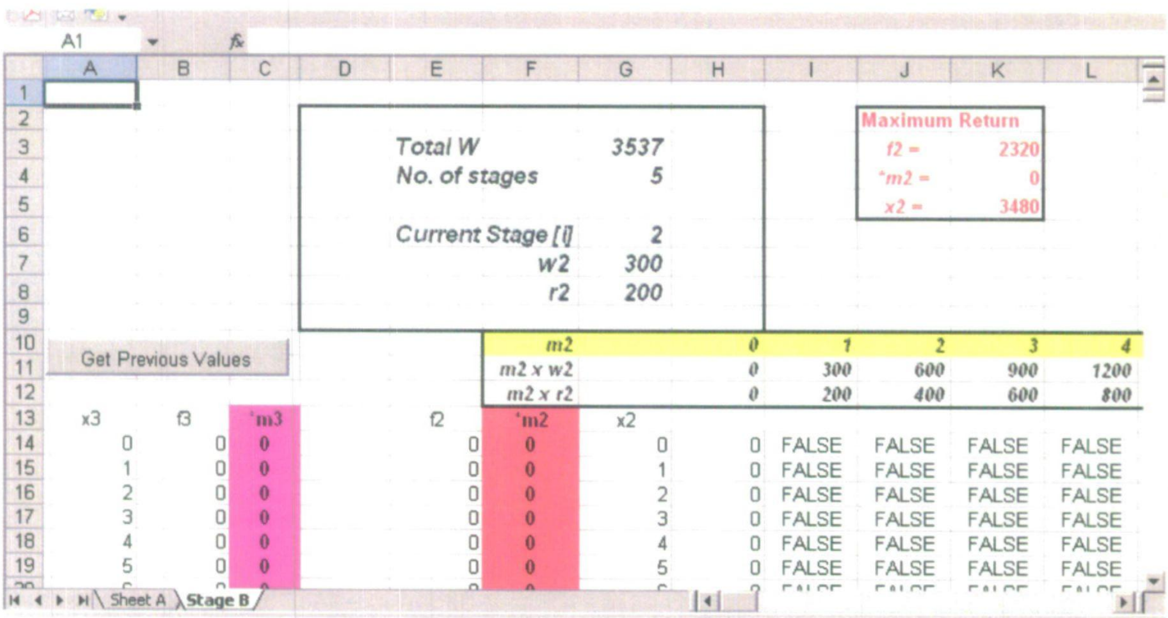


x2=3480

⇨ m2=2

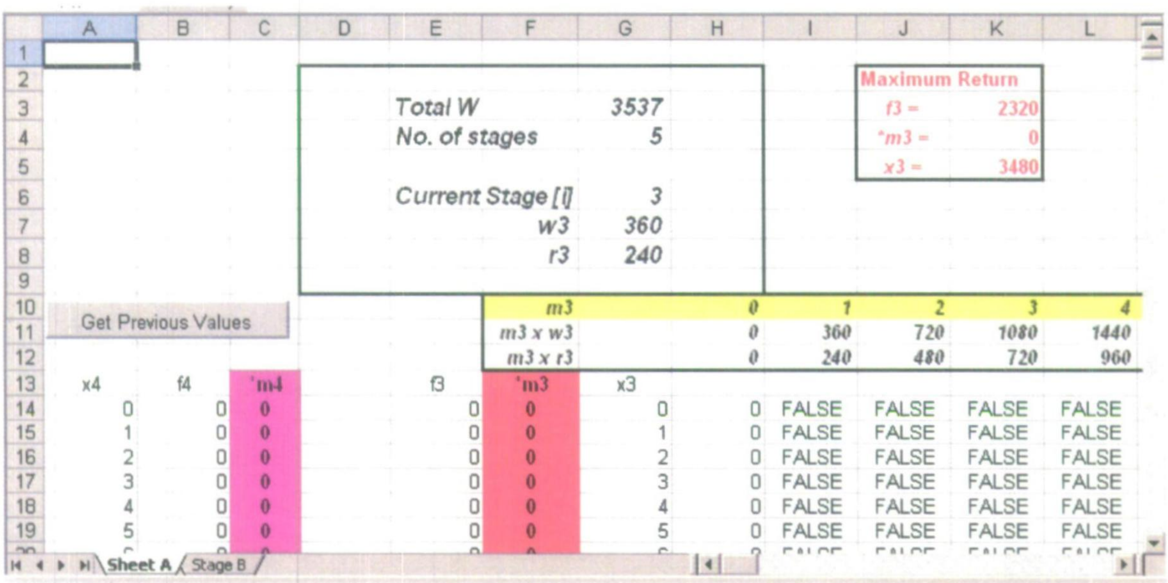
⇨ x3=x2-w2m2=3480-(480x2) = 2520

⇨ x3=3480



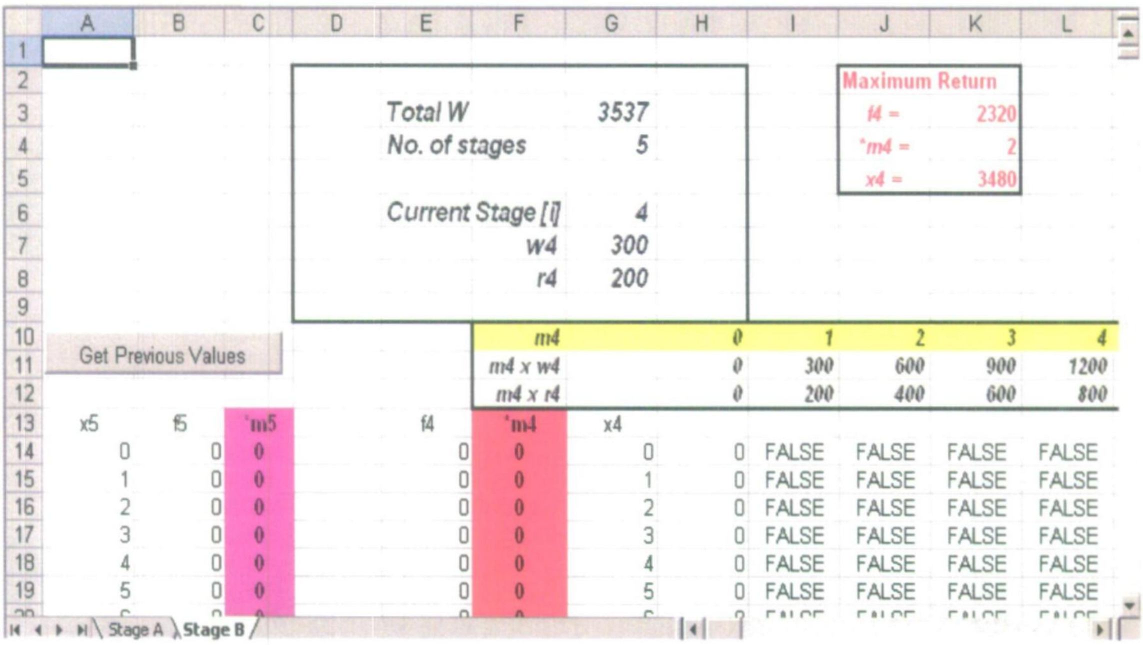
X3=2520

- ⇨ m3=0
- ⇨ x4=x3-w3m3=2520-(360x0)
- ⇨ x4=2520



X4=2520

- ⇨ m4=0
- ⇨ x5=x4-w4m4=2520-(300x0)
- ⇨ x5=2520



X5=2520

⇨ m5=14

G2534 fx =IF(((G2533+1<=G3) * (G2533<>FALSE)),G2533+1,FALSE)

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2											Maximum Return	
3					*Total W*		*3537*				*f5 =*	2280
4					*No. of stages*		*5*				**m5 =*	19
5											*x5 =*	3420
6					*Current Stage [i]*		*5*					
7						*w5*	*180*					
8						*r5*	*120*					
9												
10						m5		0	1	2	3	4
11						m5 x w5		0	180	360	540	720
12						m5 x r5		0	120	240	360	480
13	x6	f6	*m6		f5	*m5	x5					
14					0	0	0	0	FALSE	FALSE	FALSE	FALSE
15					0	0	1	0	FALSE	FALSE	FALSE	FALSE
16					0	0	2	0	FALSE	FALSE	FALSE	FALSE
17					0	0	3	0	FALSE	FALSE	FALSE	FALSE
18					0	0	4	0	FALSE	FALSE	FALSE	FALSE
19					0	0	5	0	FALSE	FALSE	FALSE	FALSE