Design and Analysis

Of

Queuing System

ENSE 622 Systems Engineering

Submitted by

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ABSTRACT

This systems engineering design project takes a detailed look at the issuance of boarding passes at a particular airport. The airport has fixed space to provide to the airlines that in turn set up their boarding pass counters. Given this space constraint, the airlines share counters with their partner companies to minimize their operating costs. The path that a passenger needs to take in-order to reach the counter is again dynamic. The line can curl and wind or can be a straight line to the counter. Given such a dynamic system structure, a systems engineering approach is applied to the problem to formulate them. The concurrent behavior of the system is modeled and a trade-off analysis is performed.

INTRODUCTION

Offering services of the highest quality is of utmost priority for airlines. This decides to a major extent the demand of passengers they obtain. Of course, the cost of tickets too play a major factor – but to determine an optimal cost for the tickets, the airlines need to determine the operating cost and how to optimize them. Given fixed resources, they need to come up with excellent quality. Considering the vast amount of operations they do, we have considered a particular operation – boarding pass issuance and have developed a systems engineering perspective of the same.

The airport has a fixed space for the airlines to set up their counters for their operations. The airlines bid for the slots and they are given a fixed number of counters – over a long-term lease. While having large number of counters will be good when demand is high, not at all times are this feasible – for they cost a lot for the airlines. Generally, airlines share the counters on a mutual agreement. A particular airline might service winter destinations and might have lot of demand in that time. Another airline might offer service to summer destinations and hence their summer demand will be high. It is mutually beneficial for both of them to share counters so that over the course of the year, their operating costs are relative to the service they offer.

With this background, we have performed a study on how do we come up with a systems engineering design for the following problem:

Two partner-airlines have in together a fixed number of counters for their operation. How do they mutually decide on the number of counters that they need to operate at a given time of the day?

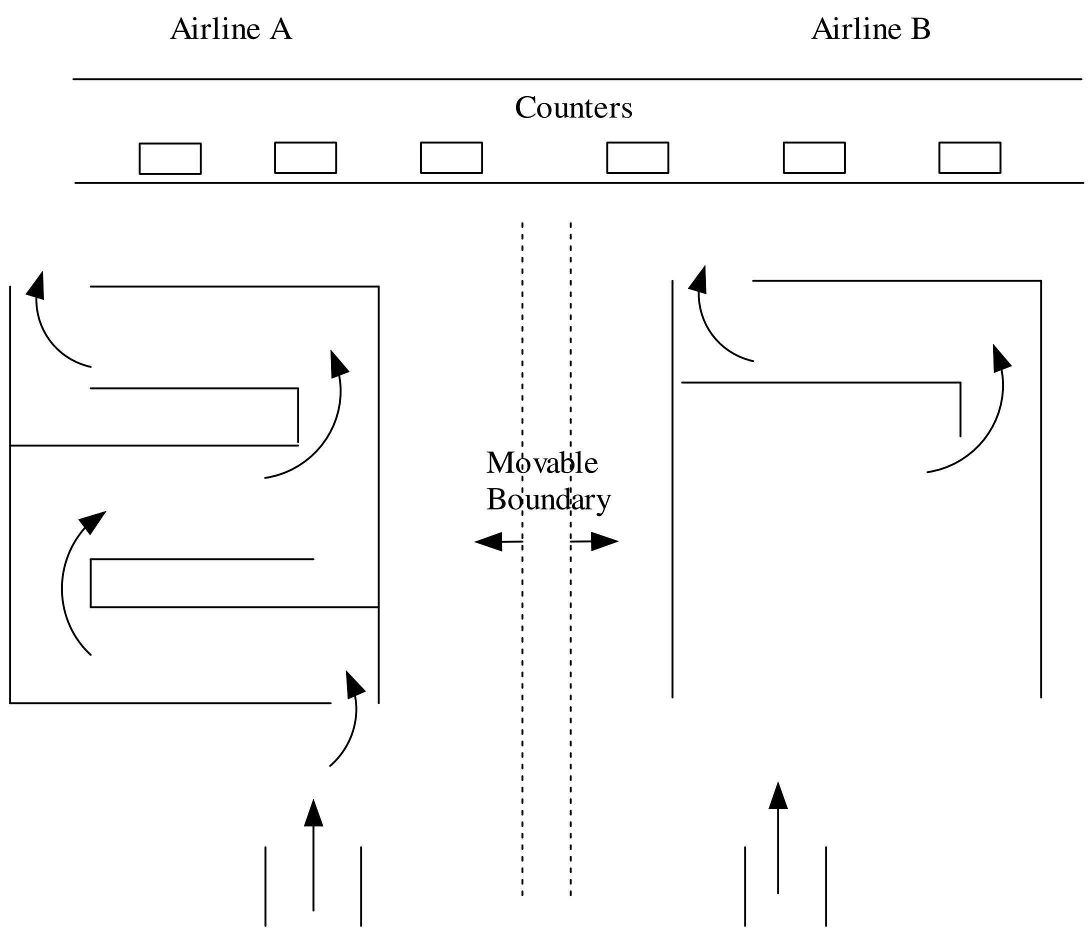
When the counters are decided, they need to set up their queue length for the passengers to come and stand in line. The queue boundary is a mobile one. They can be adjusted knowing the demand expected. The airlines know the demand they are going to expect at particular time. Hence, they can decide whether the passengers need to stand in a twirling path (like a maze) or come directly to the counters in a single line. The number of bends in the line is a decision issue. When there is a huge rush, the number of bends is high and the bends are very low when the rush is low.

When passengers arrive later than the prescribed boarding time for a particular flight – say 15 min before the departure of the flight, the airlines need to process the passenger immediately. Otherwise, it will cost for the airlines to reaccomodate him in a later flight. Hence, 30 min before the departure of the flight, announcements are made every 5 minutes requesting passengers departing for that flight to come forward (basically jump over the queue). They are processed in the first available counter. Also, there are a lot of people require special services – eg., elderly people, sick people, etc. Hence, they are also processed as and when they come. The implementation of special services offered differs from airline to airline. The issue of how airlines model such behaviors is studied here.

Hence, our project deals with the following objectives:

1) How do two airlines share the counters? How many counters are operated by each of them at a given point of time?
2) What is the queue length set at a given point of time for passengers approaching the counters?
3) How are special service-issues handled by the airlines?

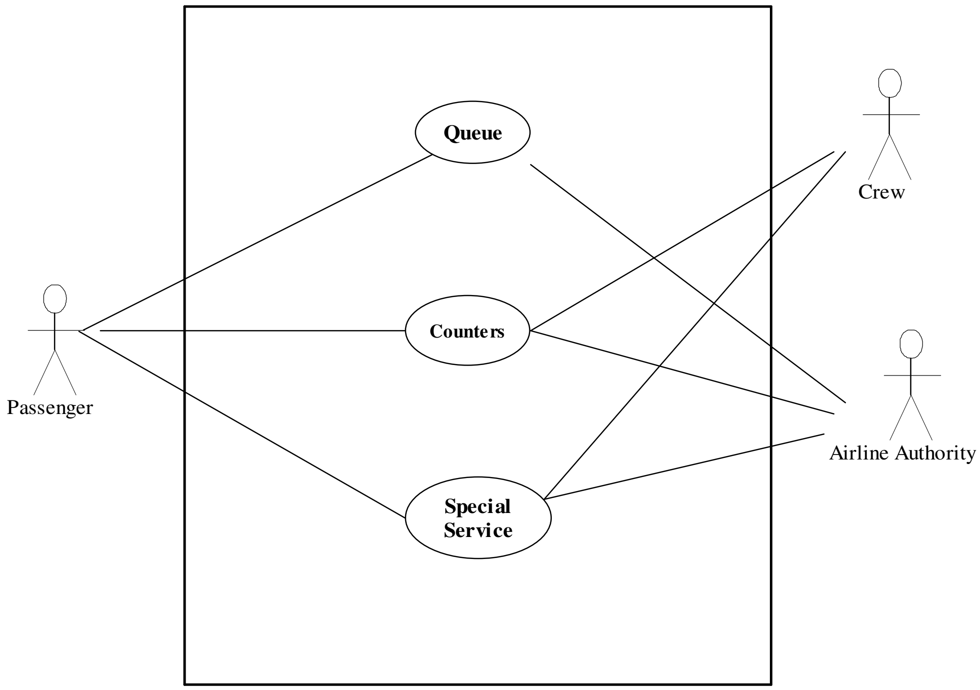
The following diagram represents a typical airport set-up where two airlines are placed next to each other. They share the counters. A mobile boundary exists between them – but the total space is limited. The queue length for each airline needs to be determined. Also, handling of special services is to be decided by the airlines.



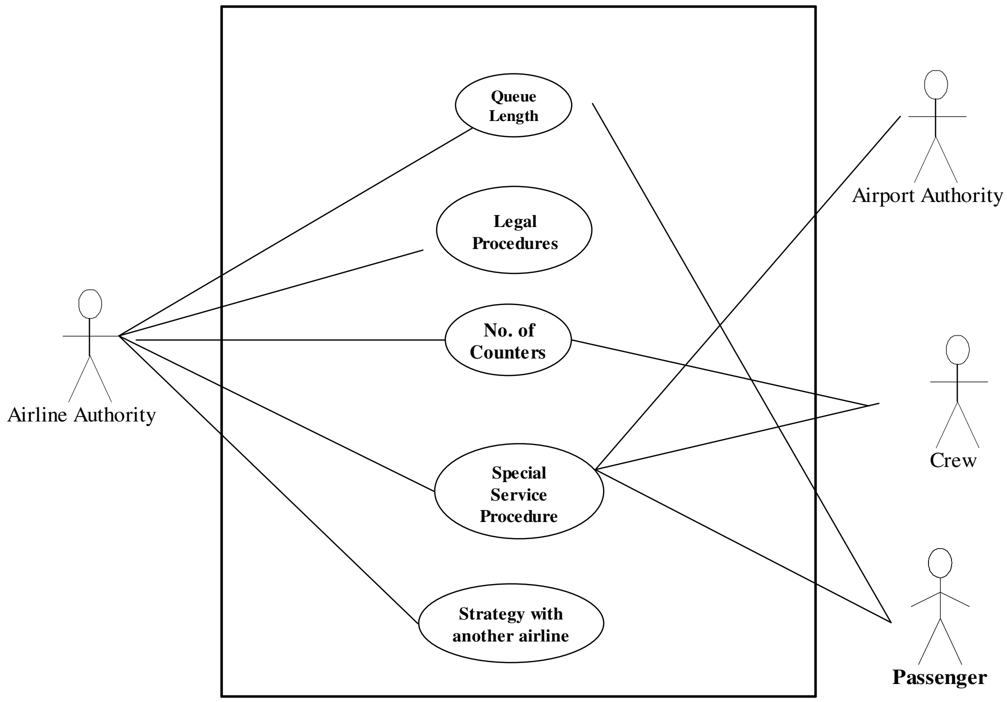
Typical Boarding Pass issuing-counter Setup

Initial Use Case Modeling and Activity Diagram

Initial Use Case Diagram



Use Case Diagram – Passenger Perspective



Use Case Diagram – Airline Perspective

Use Case A. Boarding pass issuance

Description: The passenger obtains the boarding pass – from passenger's perspective

Primary Actors: Passenger, Crew

Pre-Conditions:

- Crew members are properly trained
- Passenger knows the airline counter location where he needs to obtain the pass.

Flow of Events:

A-1. Ministry of Agriculture requests that the fishery statistics program conduct its annual collection and analysis

A-2. Local managers make collection schedules

A-3. Schedule meets minimum sampling requirements per landing point

A-4. Adequate numbers of full-time collectors are employed to travel to landing points

A-5. Adequate numbers of part-time local collectors are employed to collect at inaccessible landing points

A-6. Appropriate pay rates are included in the scheduling

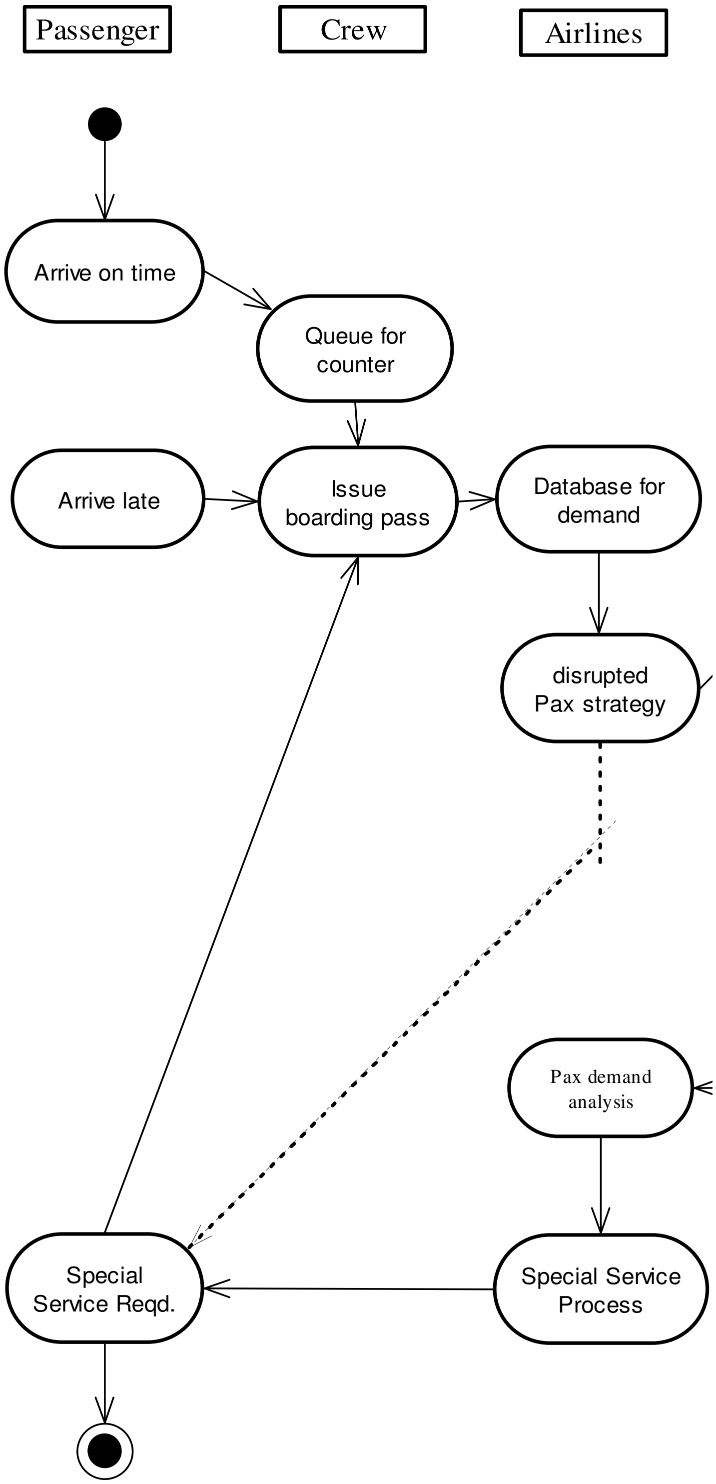
Post Conditions:

- Passenger either misses the flight or obtains the boarding pass on-time to catch the flight.

Alternate Flow of Events: In case of passenger missing the flight, airlines need to take appropriate measure to decide whether to compensate the passenger or not.

Assumptions:

- None


Passenger
Crew
Airlines
Arrive on time
Queue for counter
Arrive late
Issue boarding pass
Database for demand
disrupted Pax strategy
Pax demand analysis
Special Service Reqd.
Special Service Process

Use Case B. Determination of Counters/Queue Length

Description: Airlines need to determine the number of counters and the optimal queue length which the passengers have to traverse in order to get the boarding pass – From Airlines perspective

Primary Actors: Airlines, Crew, Partner-Airline, Passenger, Airport Authorities

Pre-Conditions:

- Airport authorities to airlines allocate fixed number of counters.
- Two airlines share the counters.
- Passenger demand at a given point of time is known.

Flow of Events:

B-1. Passengers arrive at the correct landing point per their schedule

B-2. The demand at a given time is known. Hence the queue length is set.

B-3. The airline and its partner airline mutually decide to share counters as per their demand at a given point of time.

B-4. Adequate crew members are allocated.

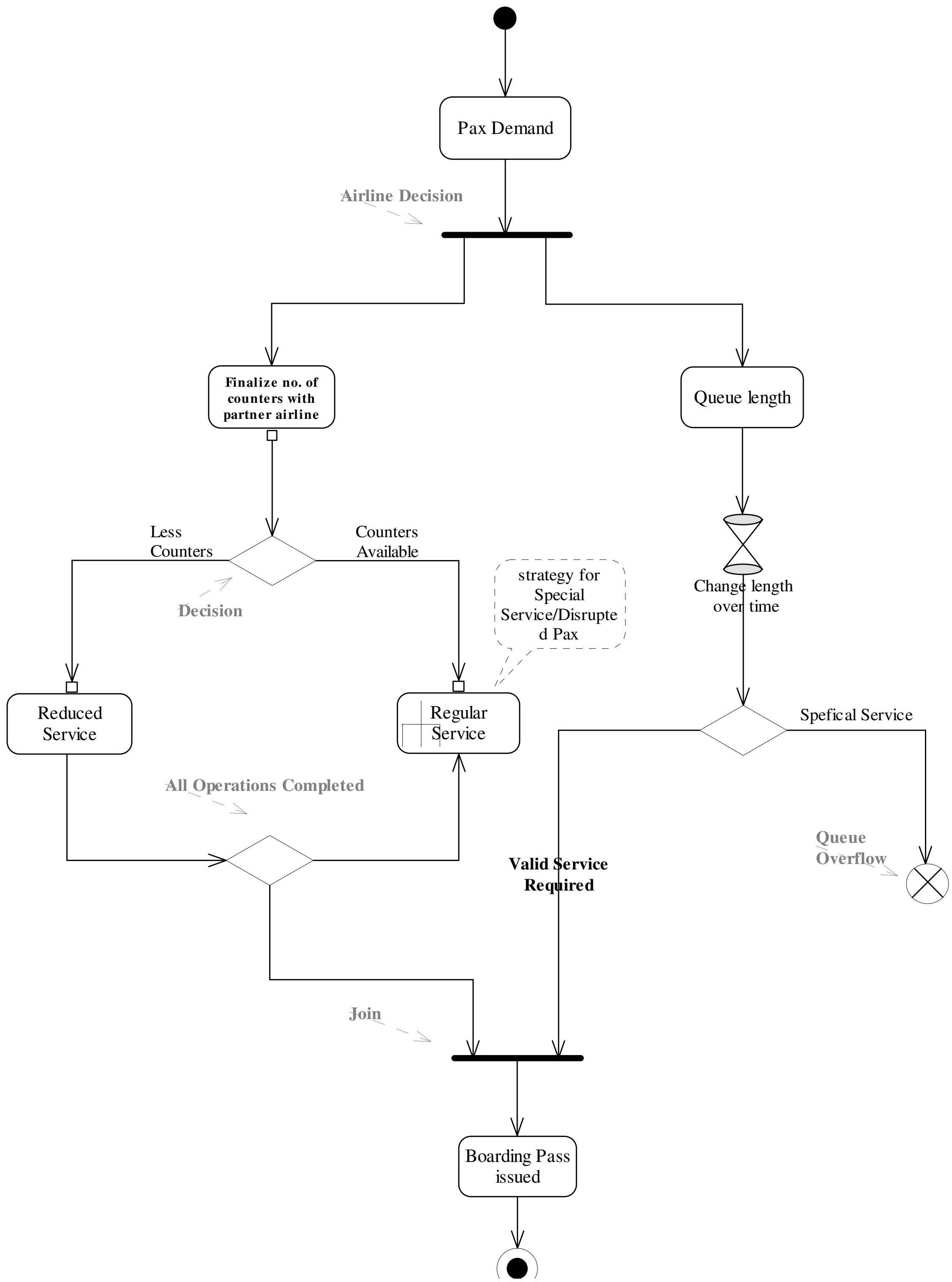
B-5. Process for special services-required passengers is determined.

Post Conditions:

- Passenger boards plane or compensated appropriately.

Alternate Flow of Events: None

Assumptions: None


Pax Demand
Airline Decision
Finalize no. of counters with partner airline
Queue length
Less Counters
Counters Available
Decision
strategy for Special Service/Disrupted Pax
Change length over time
Reduced Service
Regular Service
Spefical Service
All Operations Completed
Queue Overflow
Valid Service Required
Join
Boarding Pass issued

Goals and Scenarios

Goal 1. Proper queuing mechanism should be setup for passengers arriving on time.

Scenario 1.1. Arriving passengers wait at the lounge till their flight announcement is made.

Scenario 1.2. Once announcement is made, passengers join at the end of the queue that leads to the counters for issuance of boarding pass.

Scenario 1.3. There is just a single queue. Once a particular counter is free, the next passenger in line gets serviced.

Goal 2. Separate Queuing Mechanism for passengers arriving late

Scenario 2.1. Passengers might typically come later than the initial check-in time suggested. (Eg: 15 min before flight take-off). 20 min before the actual flight take-off, an announcement is made to determine the passengers who aren't yet processed for that flight. Those passengers get processed immediately by the service team.

Scenario 2.2. Care is taken as not to allocate all the counters to such late-passengers as it penalizes people arriving on time for the next flight.

Goal 3. Flight Announcement should be made at proper time

Scenario 3.1. Passengers waiting at the lounge should be given a first call-for picking up ticket issuance 90 minutes before flight taken. After that every 30 min a call is given and when just 20 min is left for take-off, a separate mechanism is activated.

Scenario 3.2. The passengers should join the queue.

Goal 4. The service-team size should be of optimal size

Scenario 4.1. The service team shouldn't be either in shortage or in excess. Proper trade-off is carried out to determine actual team size at a given time interval.

Scenario 4.2. Breaks and change of team members should be done smoothly.

Goal 5. Mechanism for passengers missing flight

Scenario 5.1. If passenger arrives after flight has taken-off, he has to buy another ticket.

Scenario 5.2. If passenger misses flight because of either connecting flight delay or because of the delay caused by the service team, adequate measures are taken to compensate the passenger and to ensure that he takes next available flight.

Goal 6. The efficiency and effectiveness of the system should be high

Scenario 6.1. The quality and cost of service provided should be at optimal.

Scenario 6.2. Periodic assessments of the various parameters are to be carried out to ensure that efficiency and effectives are maintained at the highest level.

Scenario 6.3. The system should be highly reliable and feasible.

Scenario 6.4. The mean service rate should be optimal considering the mean arrival rate of passengers.

Goal 8. The service team should have support personnel

Scenario 8.1: There should be enough support personnel to take care of unprecedented events.

Scenario 8.2: There should be a maintenance Training/Support Team

Goal 9. The system should be capable to withstand active and/or rigorous usage.

Scenario 9.1. Even when the number of passengers arriving at a particular time exceeds the normal arrival rate, the operations should be carried out efficiently.

Requirements Traceability Matriz

	Requirements	Goal	Scenario
	Management Requirements		
M1	The system must be reliable.	8,9	8.1,9.1
M2	The cost of the system must be minimum.	6	6.1
M3	The utilization of each employee must be at least 80%.	4,6,8	4.1,8.1,8.2
	Airline Requirements		
A1	The passengers must be able to check-in in time for the flights.	2,3	2.1,3.1
A2	The system must be able to handle the flight schedule changes.	3	3.1,3.2
A3	The system must make sure all the passengers already issued boarding passes are cleared for security from all database.	6	6.1
	Crew Counters Requirements		
C1	The system must be able to handle any queue size.	4,8,9	4.1,4.2,8.1, 9.1
C2	The system should have at least a supervisor available at all time to solve problems and make decision.	6	6.1,6.2,6.3, 6.4
C3	The system must be able to handle late passengers and flight schedule changes.	5	5.1,5.2
C4	The late passengers must have priority to get the service.	2	2.1
	Passengers Requirements		
P1	The wait time in the queue must be as short a		6.3,6.4
P2	The processing time for check-in time must b		6.3
P3	The passengers must be able to board on the	[illegible]	2.1,3.1
P4	There should be an alternative way if passenger missed the flight.	5	5.1,5.2

Security and Time Requirements

Security Requirements

S1 The passenger must have valid identification and/or documents.
S2 The passenger must be cleared from police criminal warrants.
S3 The passenger must be cleared from terrorist lists.
S4 The system must be able to report to security officer if there is any suspicious activity or passenger.

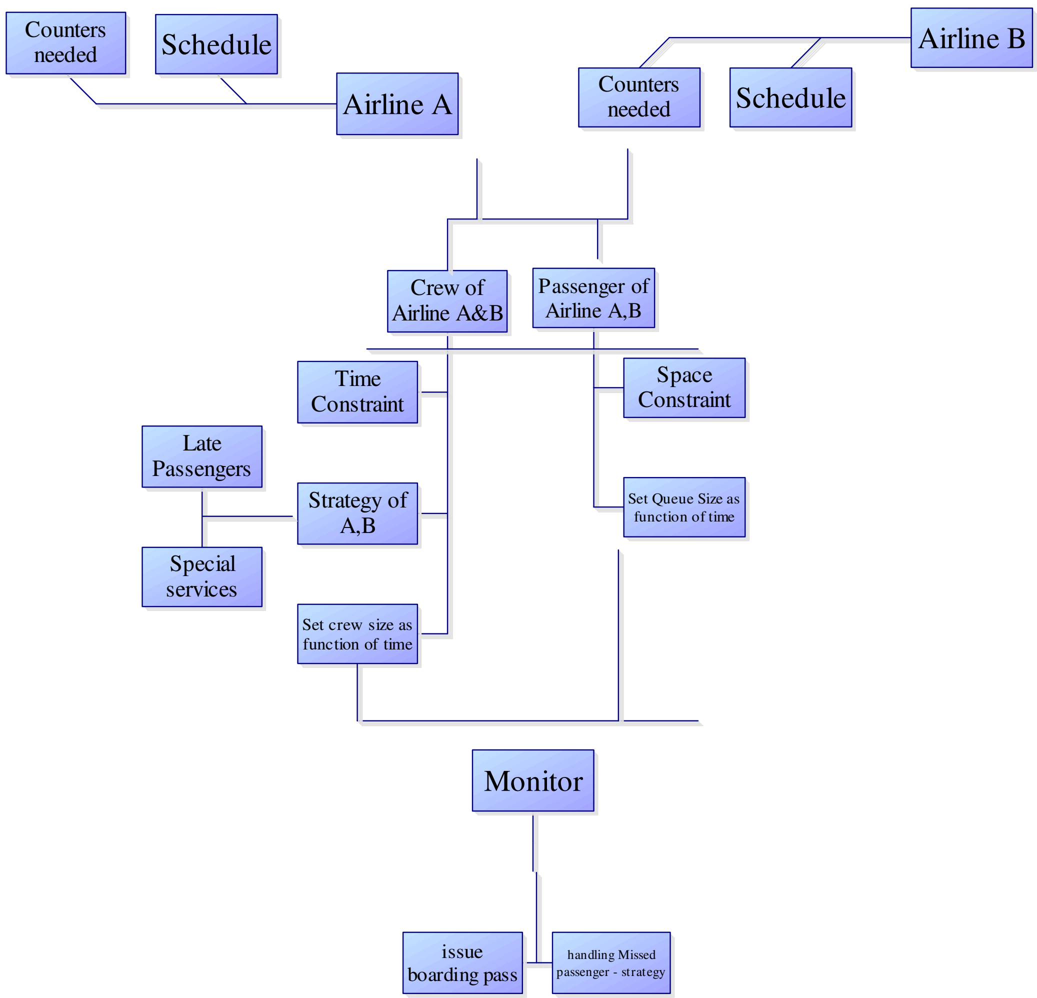
Timing Requirements

T1 The waiting time of any passenger in the queue must be less than 15 mins.
T2 The number of passengers in the queue at any time must be less than 10.
T3 The service time of any passenger must be less than 10 mins.
T4 Any late passenger must get service in less than 3 mins of waiting time.

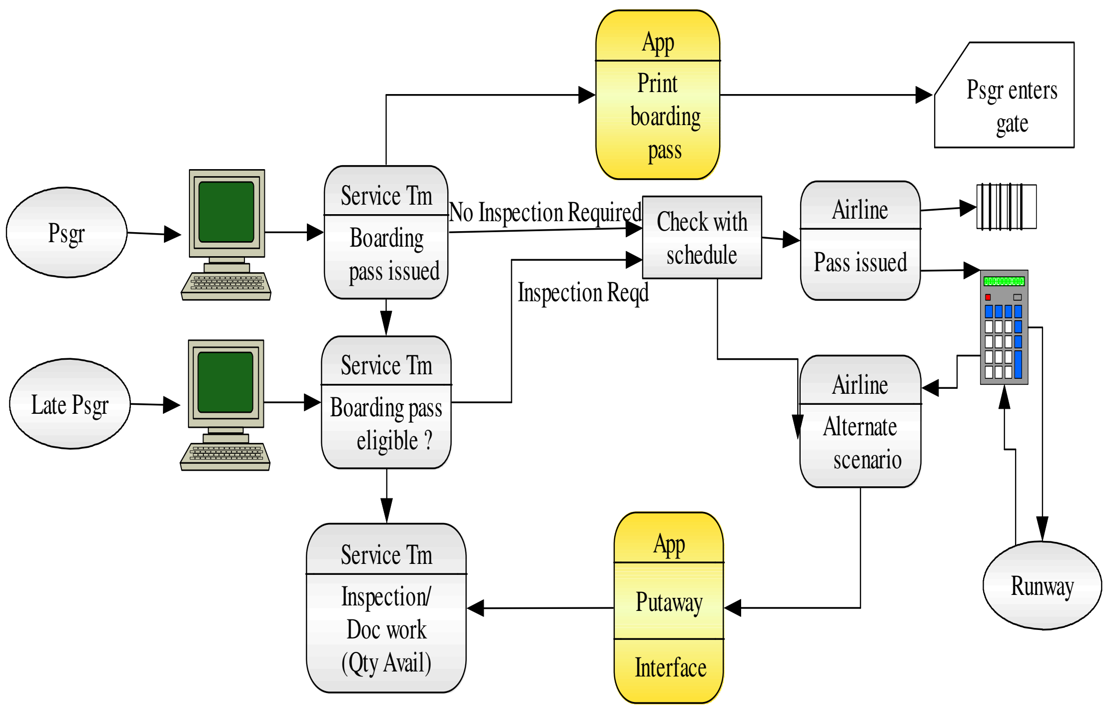
In the current Project, we do no consider security arrangements while modeling and validating the state and structure of the behavior.

System Structure

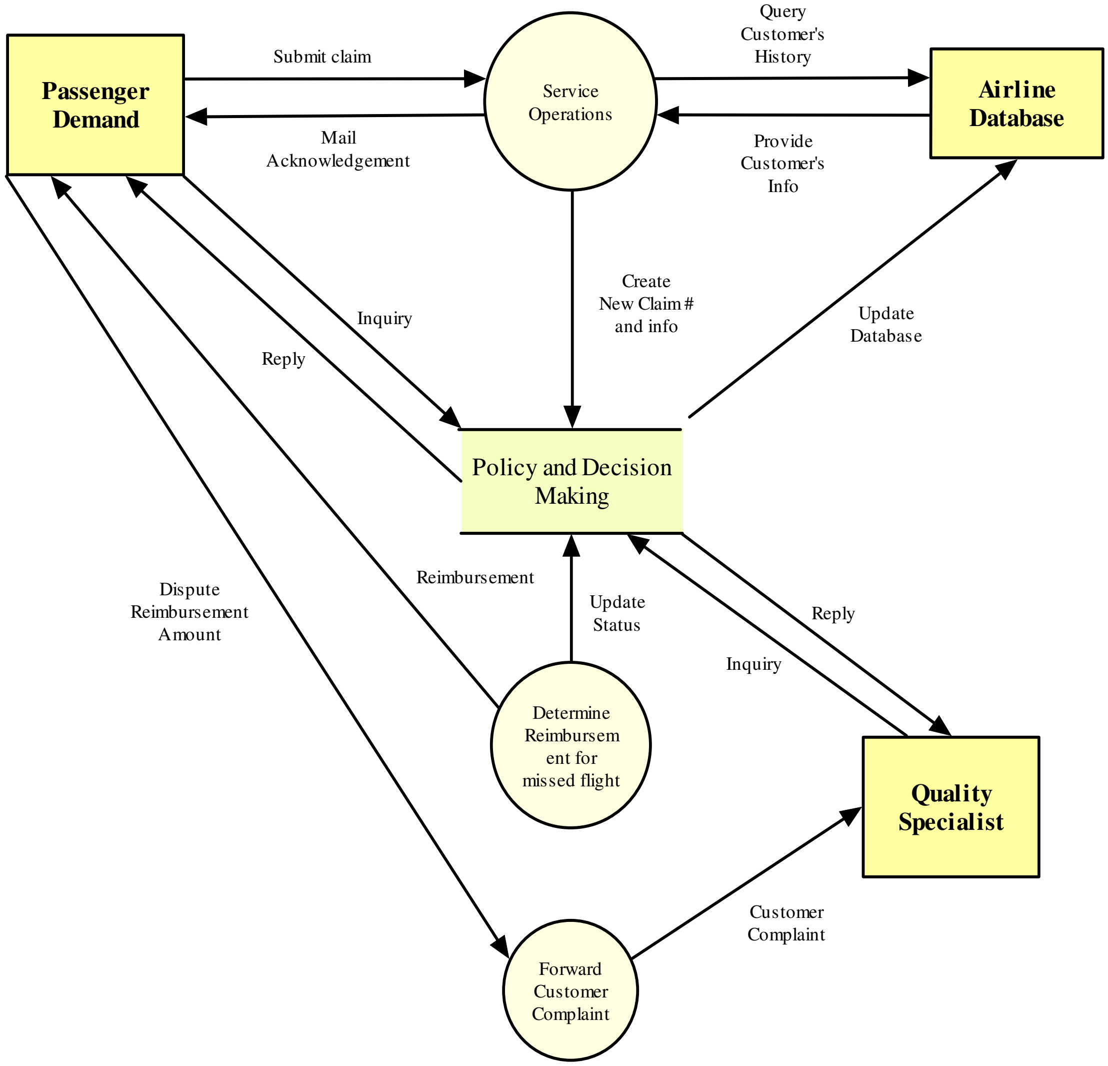
The system structure for the boarding pass issuance is given as follows:



System flow from Passenger viewpoint



Context Diagram

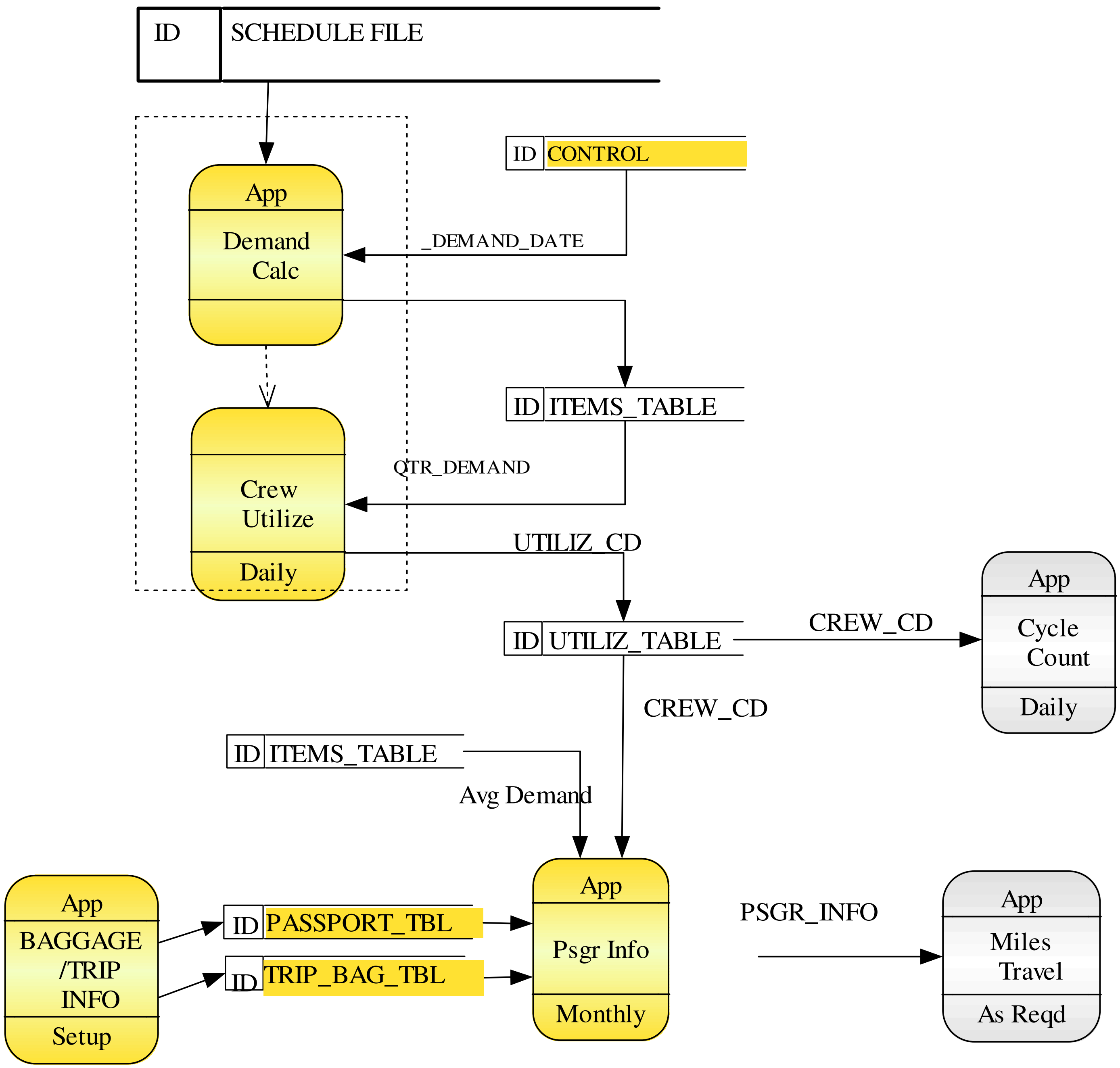


The context of the project within airline's scope of management is represented by the above diagram.

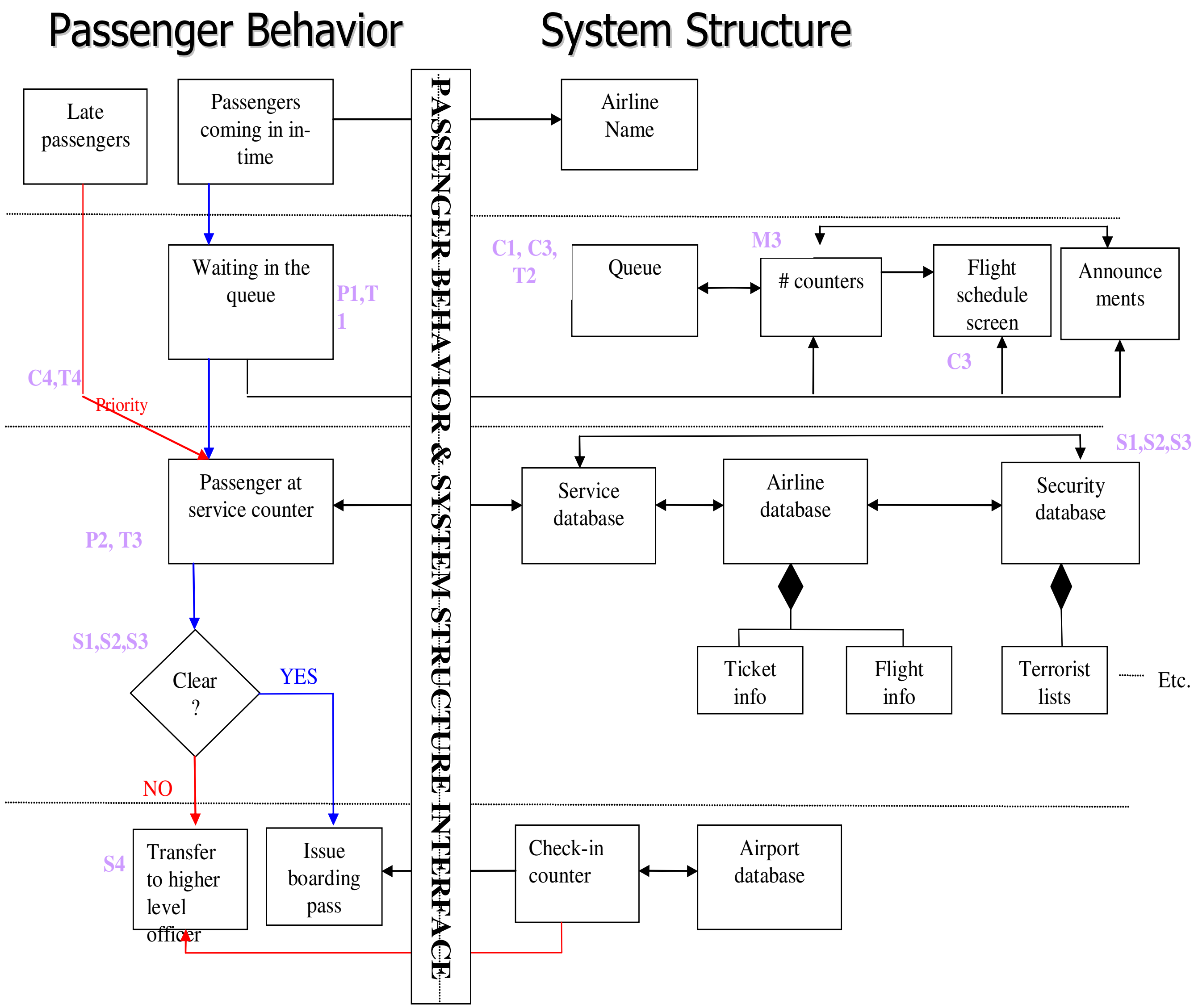
Passenger Information flow

The airlines track pax information in order to anticipate demand at given point of time. The tracking of passenger flow is as follows:

Passenger Information Flow



Mapping of System structure and behavior



The above diagram shows the queuing system structure and behavior and how they are mapped at each stage of passenger action.

When a passenger walks into the lounge, he has to look for the airline name first. So the interface for communication between behavior and system is the airline name.

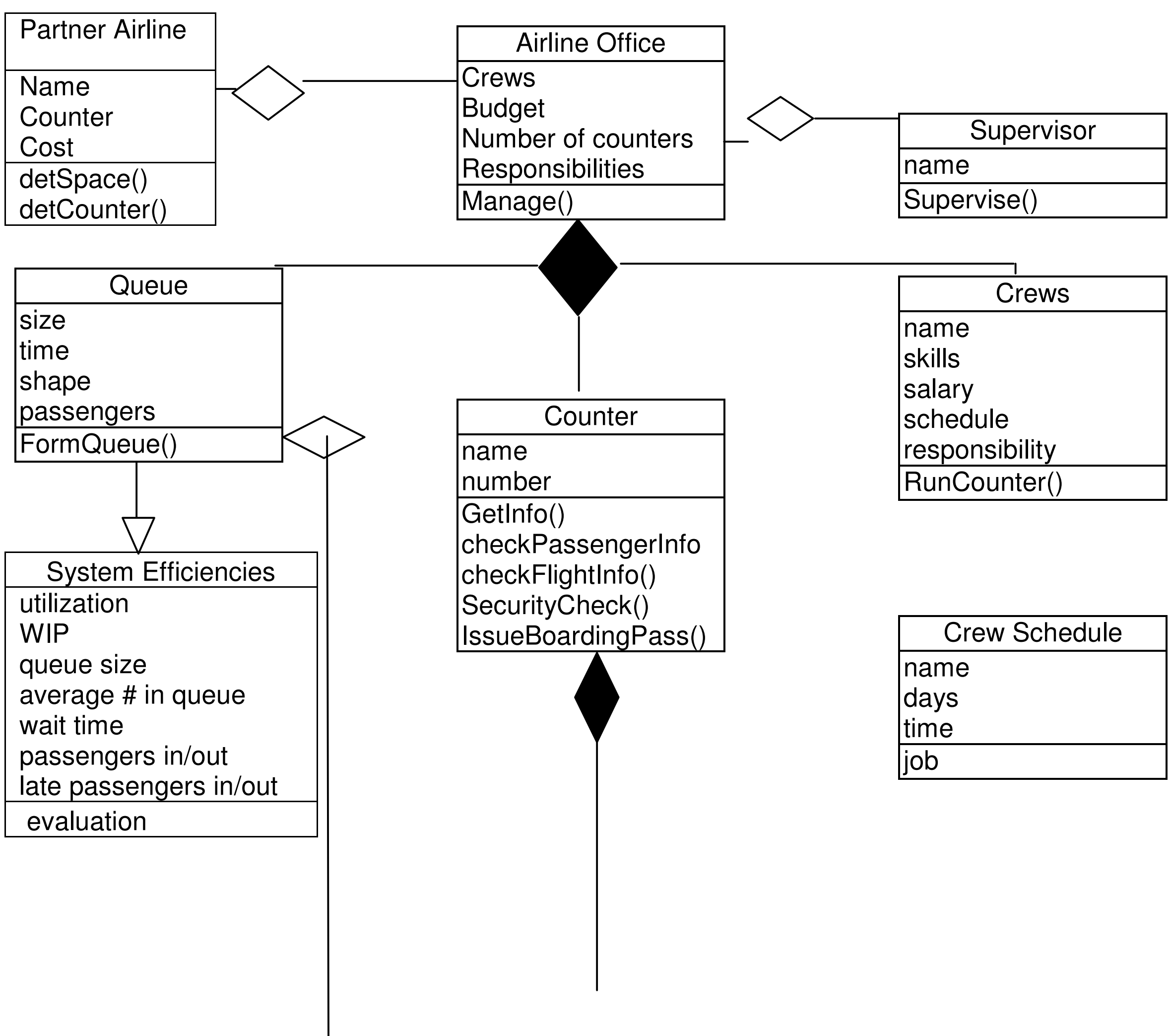
Now the passenger is waiting for the service in the queue which needs to conform to requirements P1 and T1. On the structure side, there are queue with requirements C1, C3 and T2, number of counters (M3), Flight schedule screen (C3) and Announcements. The counters have to interact with flight schedule, queue and announcements in order to know the departing flight, adjust the number of counters and to be able to serve the late passengers in time. The interfaces for communication between behavior and structure are number of counters, flight schedule and announcements.

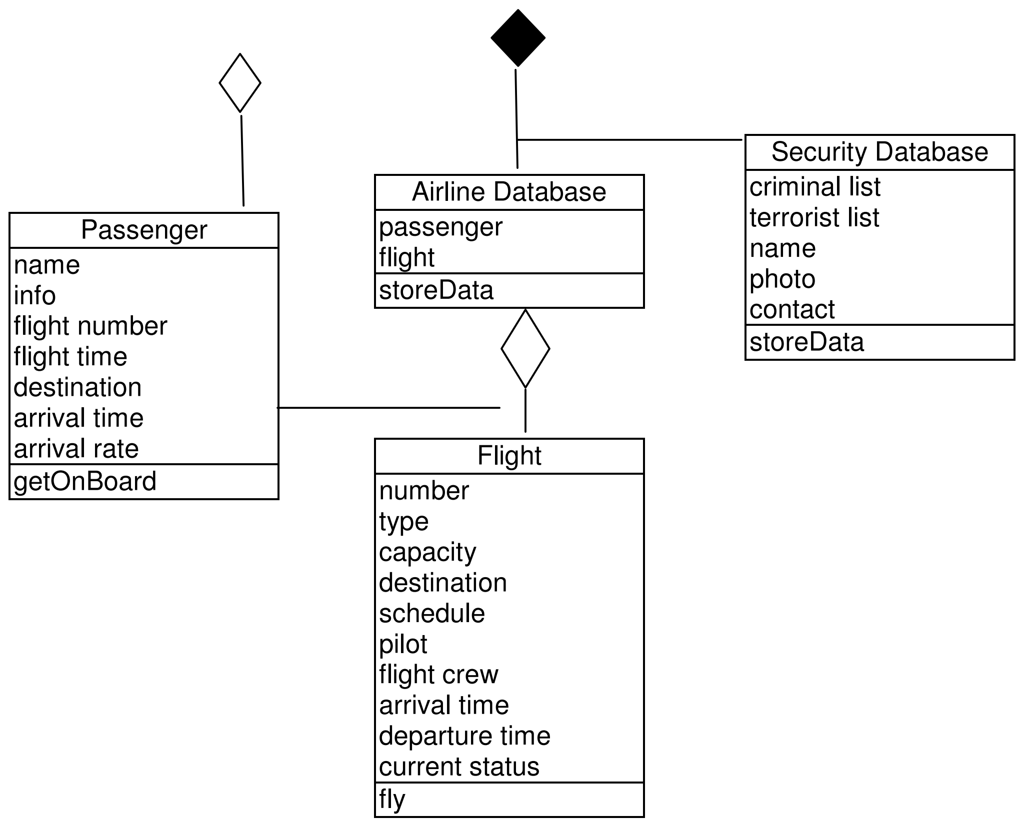
Now the passenger is at the service counter (P2 and T3). But the late passengers have priority to get the service according to requirements C4 and T4. Here the crew needs to check the service data base for the passenger information, airline data base for the ticket and flight information, and security database (S1,S2 and S3) for the security clearance.

If everything is cleared, the crew interacts with airport database and issues the boarding pass to the passenger. If not cleared, the passenger is transferred the supervisor according to requirement S4.

Class Diagram

The class diagram for the boarding pass issuance is given below





Passenger
name
info
flight number
flight time
destination
arrival time
arrival rate
getOnBoard
Airline Database
passenger
flight
storeData
Security Database
criminal list
terrorist list
name
photo
contact
storeData
Flight
number
type
capacity
destination
schedule
pilot
flight crew
arrival time
departure time
current status
fly

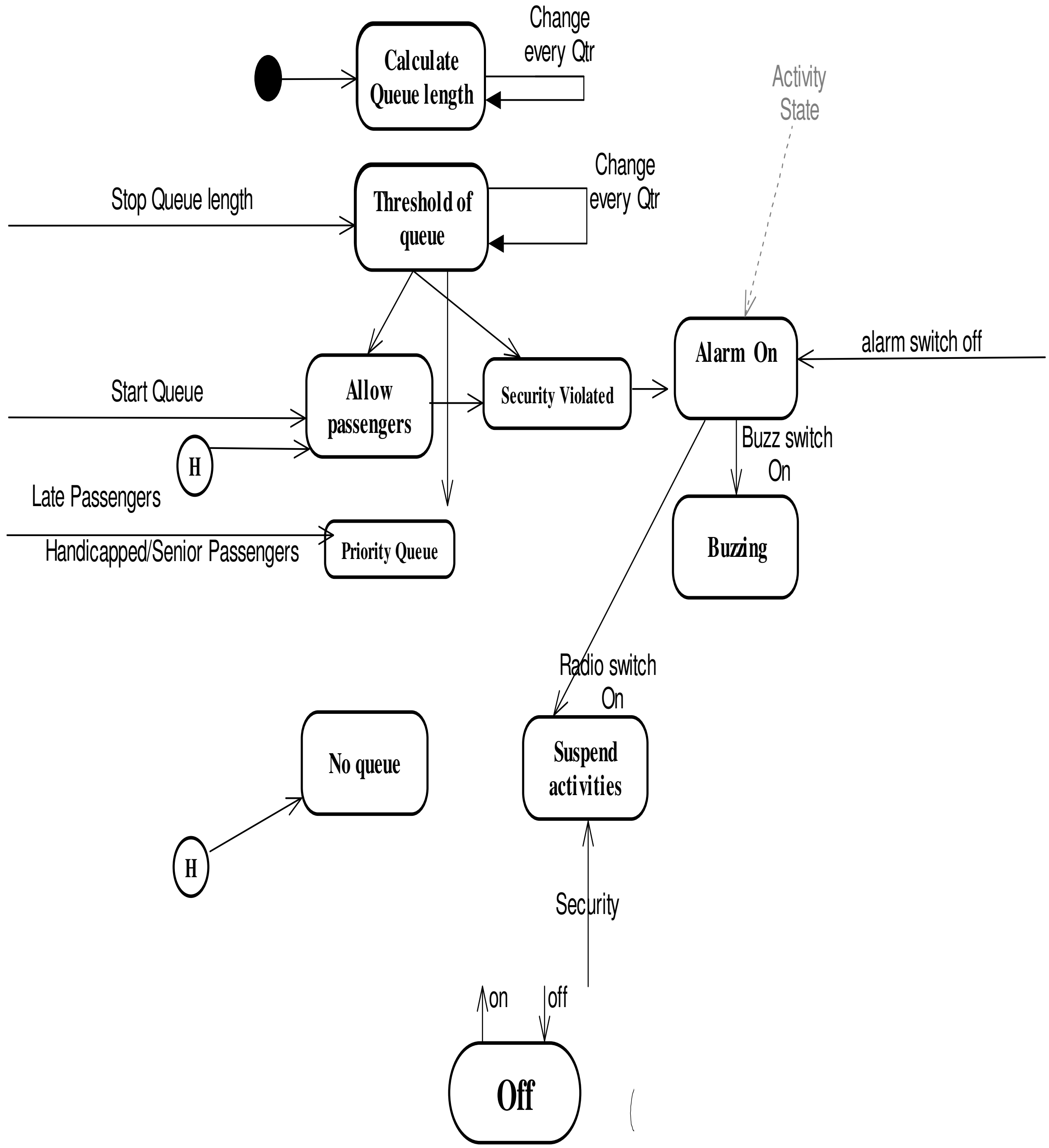
Analysis of the concurrency in the system

The system has the following concurrent aspects:

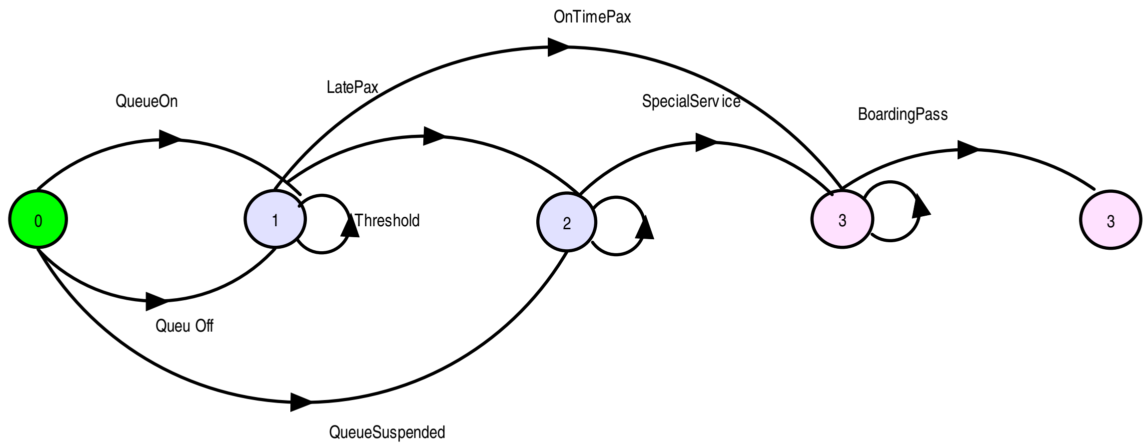
1) The queue length changes dynamically.
2) The number of counters used by the airline and its partner varies at a given point of time.
3) Passengers can be late or might require special service.

The system has to be implemented in LTSA tool to determine about implied scenario and to check the model for its validity. Also, since this is a concurrent system, we need to ensure that deadlocks don’t occur.
We have carried out a basic implementation in LTSA.
Further scope is to improve upon the basic model by implementing all the functionalities and to include timing constraints as well.

A simple implementation of the state diagram has been performed using LTSA for the following instance:
Passengers come and stand in line. The queue has a threshold limit. When the queue length reaches that, further expansion is restricted till it reduces to a certain level. Late passengers and passengers requiring special permission are processed in a timely fashion.
The output state chart is shown below.

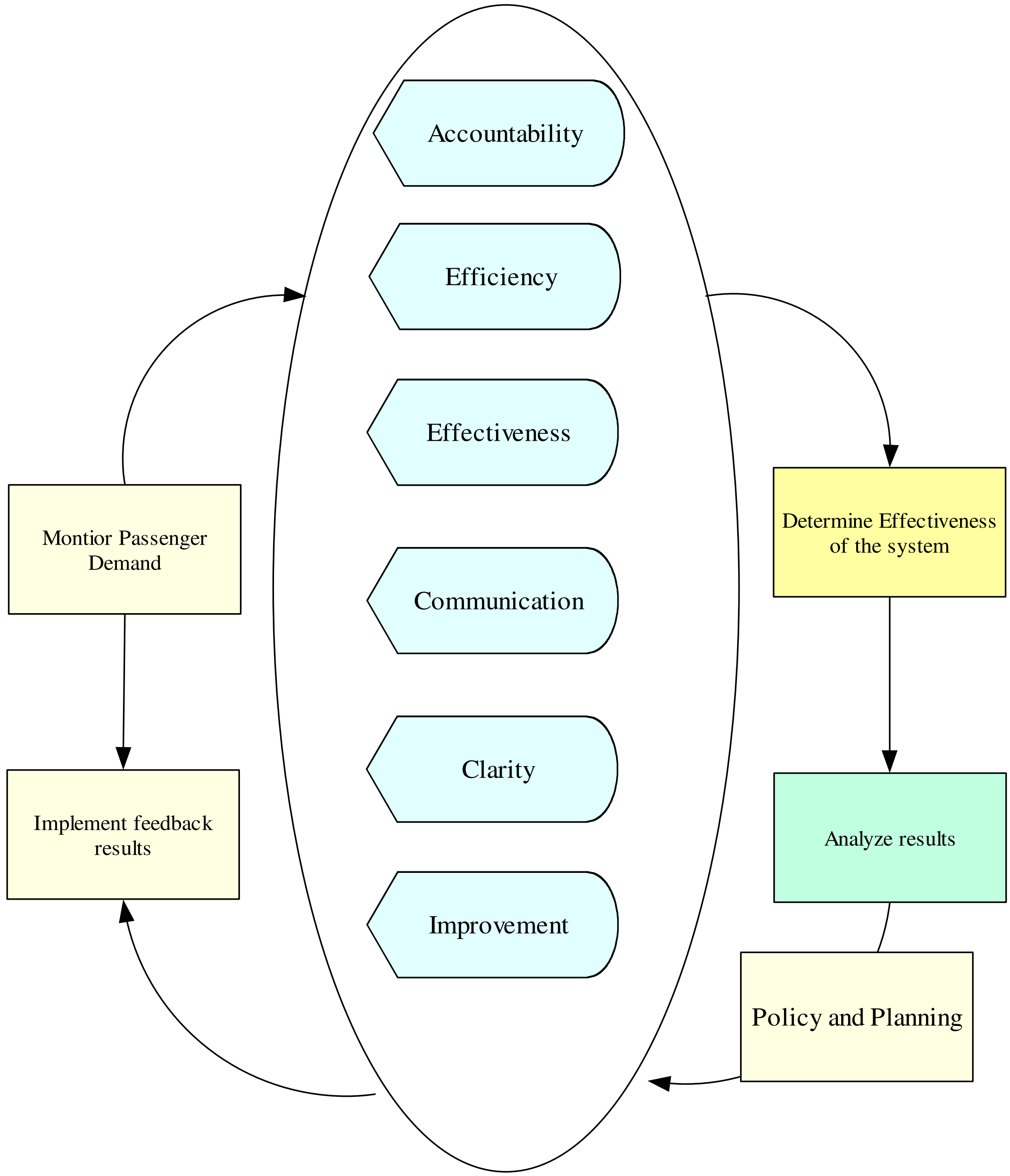


Calculate Queue length
Change every Qtr
Activity State
Stop Queue length
Threshold of queue
Change every Qtr
Start Queue
Allow passengers
Security Violated
Alarm On
alarm switch off
H
Late Passengers
Buzz switch On
Handicapped/Senior Passengers
Priority Queue
Buzzing
Radio switch On
No queue
Suspend activities
H
Security
on
off
Off



Measures of effectiveness

Some of the long term strategies to accommodate increasing demand are to expand the existing system capabilities, improving the services provided, and efficient control of traffic flow through demand management for effective operations. Even though the above are ideal measures, system performance measurement is a key factor in identifying critical points and solving them appropriately. Performance measuring is critical to the decision-making process – both for airlines and passengers.


Accountability
Efficiency
Effectiveness
Communication
Clarity
Improvement
Montior Passenger Demand
Implement feedback results
Determine Effectiveness of the system
Analyze results
Policy and Planning

The following are the key factors :

- Monitor the system.
- Quantify the performance effectiveness of the system
- Implement feedback control
- improve the effectiveness of the system

Reasons for Performance Measurement

The reasons for performance measurement are :

(a) Accountability

(b) Efficiency:

(c) Effectiveness:

(d) Communication amongst airlines

(e) Clarity:

(f) Improvement over time:

Hence, when a feedback mechanism is being proposed, the following are considered:

(i) Relevancy to Objectives

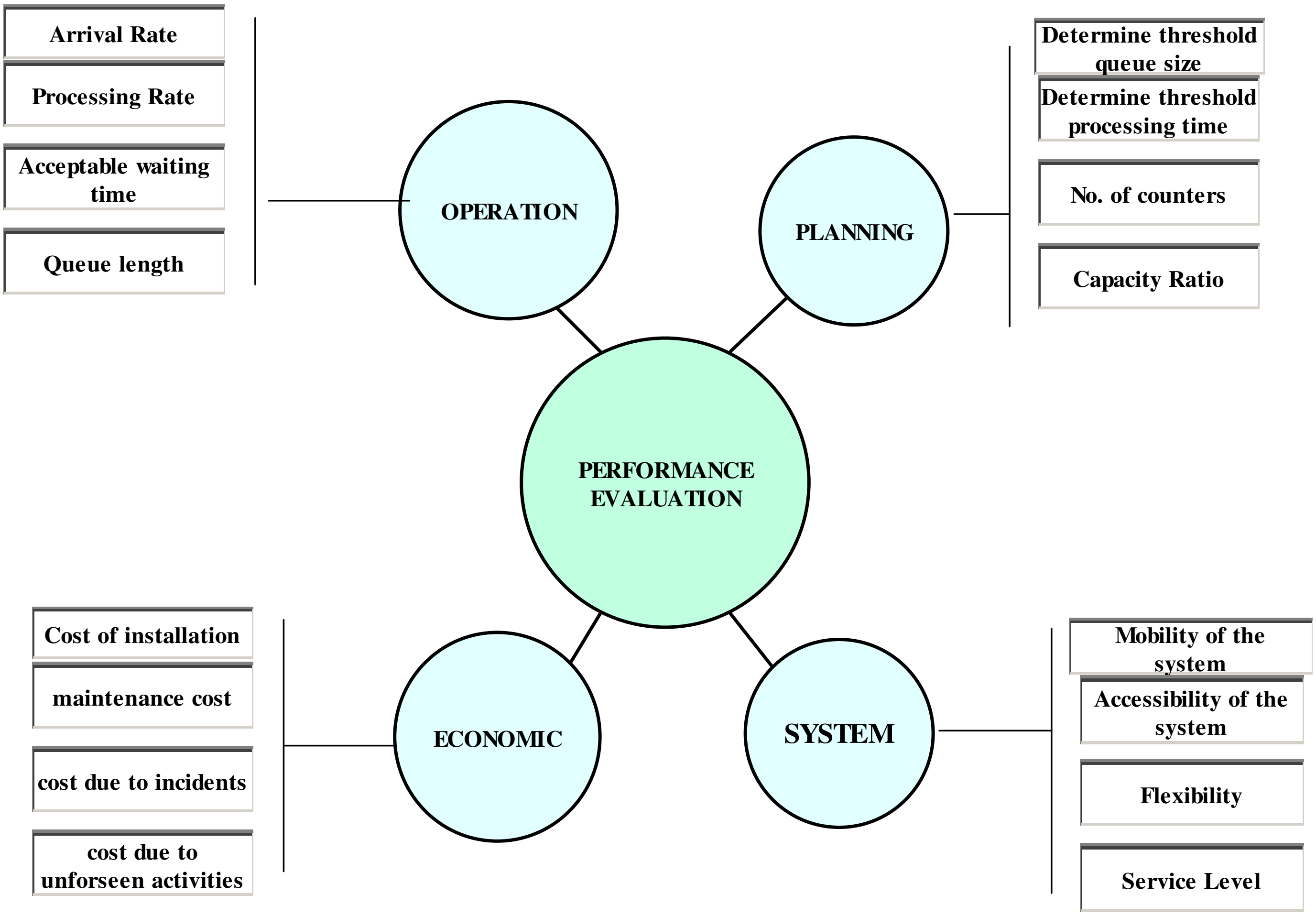
(ii) Simple and Understandable concept

(iii) Measurable and Quantitative

(iv) Sensitive and Broadly Applicable

(v) Non-Redundant

(vi) Appropriately Detailed



The above diagram shows how the systems parameters contribute to measure the system effectiveness.

Design Structure Matrices help system modeling because they represent presence of absence of relationship between a pair of entities in the system. It is very compact and the systematic mapping makes them clear and easy to read-off.

They can be used to represent the following:

1) Space

2) Information

3)Material/Activity

A number can be used to represent the usefulness or closeness amongst two entibies – say a number of +2 might signify very close and and –2 might represent detrimental, with values in between them representing lowering effect on its functionality.

Activities		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Passengers Arrive	**A**	A	X						
Queue Length set	**B**	X	B					X	
Two airlines interact	**C**			C	X				
Counters set	**D**				D			X	X
Special Processin	**E**	X				E		X	
Late Passengers	**F**						F		
Crew Size	**G**	X			X	X		G	
Boarding pass printed	**H**				X			X	H

The above shows the various interaction amongst the activities of boarding pass issuance. They can be clustered and the design matriz is shown below :

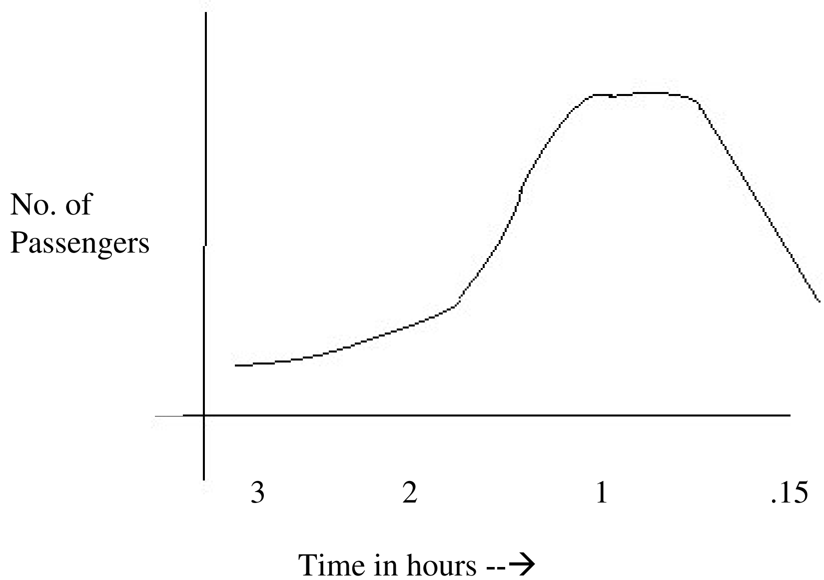
		F	**A**	**E**	**B**	**G**	**H**	**D**	**C**
Late Passengers	**F**	F							
Passengers Arrive	**A**		A		X				
Special Processing	**E**		X	E		X			
Queue Length	**B**		X		B	X			
Crew size	**G**		X	X		G		X	
Boarding Pass	H					X	H	X	
Counters Set	D					X	X	D	
Airlines interaction	**C**							X	C

Similar colors represent high interaction ie., activities that change a lot because of the indicated activities. Clustering hence allows us to visualize easily the effect of the activities. Feedback can easily be tracked.

Optimization and Trade-Offs

Trade-off Analysis

The passenger arrives for obtaining the boarding pass in the following pattern – the flow is very fewer 3 hours before the less and around one before take-off lot of passengers arrive. Hence, operation is at its peak around one hour before the flight take-off.

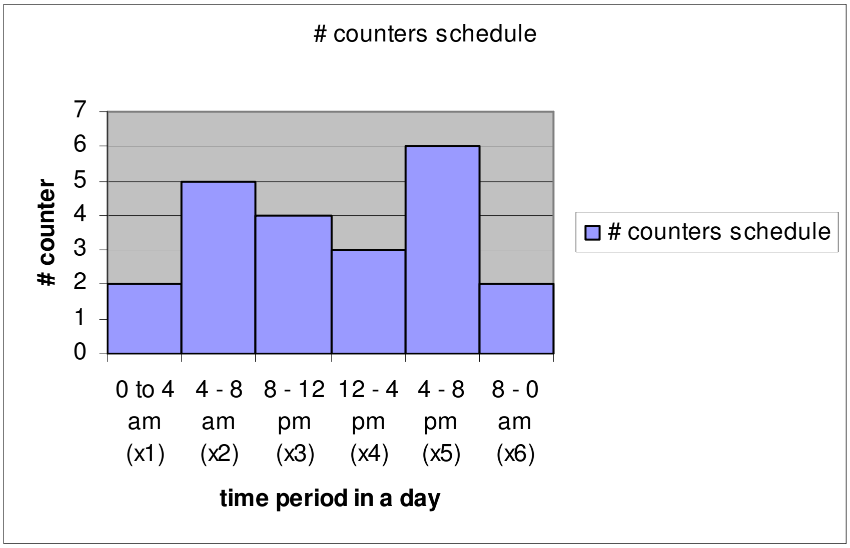


Optimization

The requirement for number of counters varies from hour to hour because of customer demand as shown in the figure. Time 0 on the figure represents midnight, and times are shown with a 24 hour clock starting at midnight. For example, four counters must run from midnight to 4 a.m., while eight counters must run from 4 a.m. until 8 a.m. We assume that the counters requirements are the same every day.
The problem is to determine how many crews to schedule at each starting time to cover the requirements for number of counters. Crews work eight hour shifts that start at times: 0, 4, 8, 12, 16 or 20. For example, a crew starting at time 0 can run a counter from time 0

to 8. A crew scheduled to start at time 20 works for the final four hours of the day and the first four hours of the next day. The goal is to minimize the number of counters used. Note that although a crew can be employed for an eight hour period, there is no requirement that he runs a counter for the entire period. He might be idle for a four hour interval within the period.

The problem is to find the smallest number of counters to cover the passenger demand.



Model

Variable Definitions

$x(t)$: Number of drivers scheduled at time t, $t = 0, 4, 8, 12, 16, 20$

We assume that this problem continues over an indefinite number of days with the same requirements and that $x(t)$ is the number used in every day at time t.

Constraints

We need constraints that assure that the crews scheduled at the times that cover the requirements of a particular interval sum to the number required.

x1 + x6 >= 2

x1 + x2 >= 5

x2 + x3 >= 4

x3 + x4 >= 3

x4 + x5 >= 6

x5 + x6 >= 2

And the last constraint is to limit the number of counters at any time be less than 6.

x1, x2, x3, x4, x5, x6 <= 6

Objective

Min x1 + x2 + x3 + x4 + x5 + x6

Optimization results from Lindo,

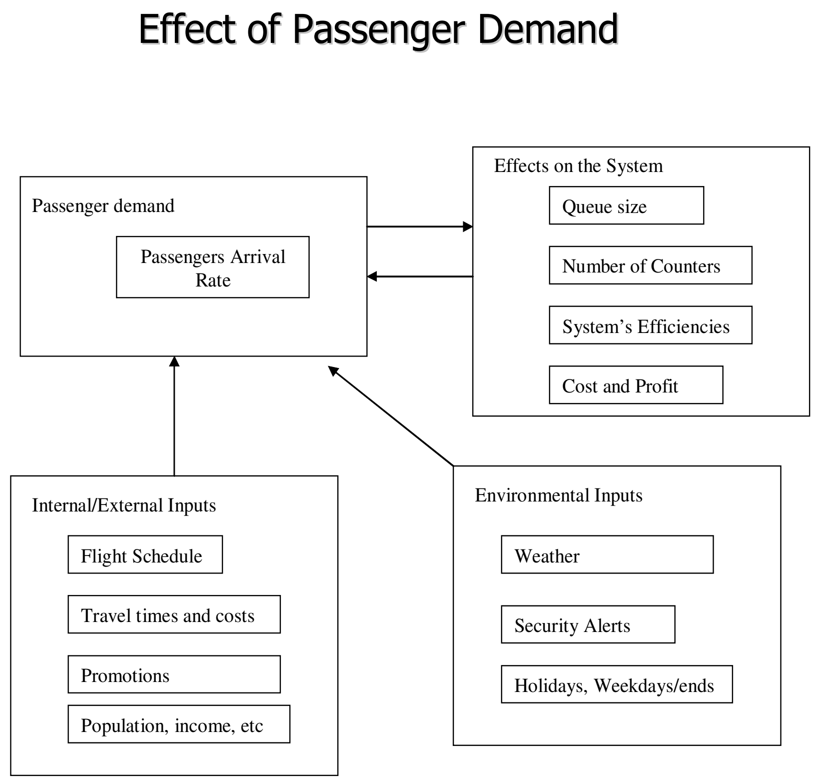
- LP OPTIMUM FOUND AT STEP 5
- OBJECTIVE FUNCTION VALUE
- 1) 12.00000
- VARIABLE VALUE REDUCED COST
- X1 1.000000 0.000000
- X2 4.000000 0.000000
- X3 0.000000 0.000000
- X4 5.000000 0.000000
- X5 1.000000 0.000000
- X6 1.000000 0.000000
- ROW SLACK OR SURPLUS DUAL PRICES
- 2) 0.000000 -1.000000
- 3) 0.000000 0.000000
- 4) 0.000000 -1.000000
- 5) 2.000000 0.000000
- 6) 0.000000 -1.000000
- 7) 0.000000 0.000000
- NO. ITERATIONS= 5

	1	2	3	4	4a	5	6
	0 to 4 am	**4 to 8 am**	**8 to 12 pm**	**12 to 4 pm**		**4 to 8 pm**	**8 to 0 am**
arrival rate	1 per 2min	1per 50 sec	1 per 1 min	1 per 90 sec	plus docu work	1 per 45 sec	1 per 110 sec
Optimized no. of crews	1	4	0	5		1	1
# of counters	2	5	4	5	5	6	2
Average utilization (%)	98.5	98.8	99	58.8	97.8	97.33	99.5
WIP(min)	7.8	15.66	14.84	2.9	4.94	6.7	12.73
average queue size	6	11	10	0	2	1	11
late # in	17	34	29	21	16	37	19
late # out	17	32	26	21	15	36	17
total # in	121	289	241	161	161	320	131
total # out	105	265	213	157	154	313	108
cost($20/hr)* Ohd rate 1.5	400	1000	800	1000	1000	1200	400

The above table shows the values of variables by employing the optimized number of crews at different time periods and trade offs for the parameters resulting from Arena simulations model. The simulation model ignores the limitation of queue size and shape at this point of time. We will employ those factors in next semester.

For example, if management wants to decrease the WIP in column 2, the number of counters can be increased. That will also decrease the average utilization and increase the number of total and late passengers getting the service. For column 4, the average utilization is low (59%) because there are only 3 counters needed for that time period but the management has to schedule 5 because of the optimized variable values from lingo. But all other parameters have better figures. The management can increase the average utilization of the crews by asking the crews to do the necessary documentation works (column 4b). That will increase the average utilization but trade offs can be seen in other parameters.

Passenger Demand Model



The figure shows the input factors for the passenger demand and arrival rate and effects on the system. The passenger arrival rate is determined by the internal/external and environmental factors such as schedule, promotions, time and cost, weather, security alerts, etc. That determined arrival rate will affect the queue size, number of counters and efficiency and effectiveness of the system.

Conclusion and Future Work

Viewpoints from the perspective of passengers and airlines have been developed. With this individual view points, the concurrent system is modeled. The issues of passenger waiting time, number of counters to be used and effective use of the limited space by two airlines by inter-dependent communication have been studied.

The challenging features of the project are

1) Concurrent behavior

2) Multiple airline multiple passenger destinations

3) Dynamic system structure

The system analysis, verification/validation of the concurrent system has to be carried out. The tool UPPAAL has to be used to validate them along with timing constraints.

References

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