Congestion Management System

SELP 695

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LMU/LA

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Background

Figure 1: Riyadh City Map

5.2 million

1800 km squared
Saudi Arabia Government budgeted $22.5 Billions
Problem Statement

86,000
in 2013 it was estimated that 86,000 people killed on t last 20 years,

8% to 23%
asthma increased in last 15 Years

financial losses $3.5 billion
Figure below shows the fear that the train stations will begin to overcrowd particularly at stations near red spotted areas seen in the map.

Figure 2: Riyadh Densely Populated Areas
Project Objective

- Lower deaths caused by driver accidents.
- Increase use of public transportation
- Reliably transport passengers to destinations
- Keep congestion at a minimum at train stations
- Minimize health concerns caused by traffic pollution
- Ultimately to help establish high morale and image of the newly built train system
- CMS will use the same routes and train station to be useful and satisfy, High Commission for the Development of Arriyadh needs.

- CMS introduce a new method to route buses so to avoid the situation of an overcrowded train station.
Description of Stakeholders

Ministry of Transportation

- Control room
- Bus drivers

High Commission for the Development of Arriyadh

Passengers of Train

Saudi Public Transport Company

Communications and Information Technology Commission
System Requirements

Functional Requirements

Technology Requirements

Performance Requirements

Utilization Requirements
Functional Requirements

1. The system shall provide the following information (to the control center):
   a. Road traffic conditions in all parts of the city
   b. Current bus routes and accurate location
   c. Occupancy of train station waiting rooms
   d. Passenger inputs of the desired direction of travel along train once at a train station

2. The system shall provide recommendations for bus drivers of which stations to take passengers

3. The system shall utilize a common interface between bus drivers and the control center for communicating
1. The system shall provide an algorithm for providing insight on best station to drop-off passengers determined by traffic conditions, waiting room capacity, and passenger input.

2. The system shall provide real-time image and data of waiting rooms at train stations to the control center via infrared camera technology and facial recognition system. The combinational use of these two technologies will allow for higher accuracy of detecting the number of people than each technology by itself.

3. The system shall be able to accommodate updates.

4. All parts of the system (including the control room & buses) shall be connected to one main server.

5. The system shall receive accurate real-time information about traffic flow from the Communications and Information Technology Commission via traffic sensors.
Performance Requirements

1. The infrared camera shall be operable during the train’s hours of operation.
2. The system should update every 15 seconds.
3. The system shall be able to provide all relevant data 24 hours a day.

Utilization Requirements

1. The infrared camera and facial recognition system should require regularly scheduled maintenance every week.
2. The system shall be accessible with a bandwidth as little as 3 Mbps.
3. The system interface among all stakeholders shall only require no more than a maximum of 1 hour of training.
The Plan - Design

- Current System
- Planned System
- Proposed System
Current System

- Only utilizes automobiles and does not have a train system (Cars and buses).
- Currently a train system does not exist in Riyadh.
- Buses are employed by many commuters but the buses act essentially as taxis and have no overarching logical system to follow.

Figure 3: Riyadh Day Time Traffic Figure

4. Riyadh Freeway Traffic
The system that is currently being built to be implemented in Riyadh utilizes an expansive train system accompanied by an armada of buses meant to encourage Saudis to take advantage of this train system. Buses take direct and set routes picking up citizens from the outskirts of Riyadh and transporting the citizens to train stations, and back.

Figure 5: Bus Route for Planned System
Proposed System

Figure 6: OV-1 High-level View of Congestion Management System
Analysis of the proposed alternative Approaches

The AoA is designed to focus on three steps defined in the INCOSE Systems Engineering Handbook (v3.2.2):

- Identify alternative solutions: the status-quo system and two candidate solutions.
- Define measures to assess alternatives, including Measures of Effectiveness (MOEs).
- Assess each alternative versus measures.
"Measures of Effectiveness provide quantifiable benchmarks against which the system concept and implementation can be compared."

<table>
<thead>
<tr>
<th>MoE</th>
<th>Car (current system)</th>
<th>Set Buses &amp; Trains (planned system)</th>
<th>Congestion Management System (proposed system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication &amp; Coordination</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>System Reliability</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>System Robustness</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>System Upgradeability</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Uninterrupted Service</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>System Safety</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>
Analysis Results

As can be seen from the analysis above both the planned and proposed systems have a clear advantage over the current state. The analysis also shows that there are many similar features between the current system with the proposed system, but the proposed system has a distinct advantage when considering the communication and coordination of the system. Most importantly, the proposed system offers better system safety and because of this the CMS is deemed the better solution among the three.
The architecture description consists of the following:
- Presentation of a defined domain
- Component parts
- How the parts function
- The rules and constraints under those functions
- How all parts relate to each other and the environment.

The architecture description consists of products that are all related and have graphical, textual and tabular items that are created from the following processes:
- Gathering architecture data
- Identifying their composition into related architecture components or composites
- Modeling the relationships among those composites
Heuristic Approach

- Don't ever try to build it all at once – evolve the system based on highest value early, and rapid learning about realities.

- Systems need to be built to tolerate change and expansion beyond current stakeholder needs.

- System Stakeholders are one more than you know about; and known stakeholders have at least one more need than you know about now.

- Risks are impossible to detail completely and correctly, but can be controlled by frequent and early numeric feedback and change – as well as creating openness for necessary change in architecture, contracts, and relationships.
Figure 7: CMS SV-4 Functional Diagram
Figure 8 below shows the data flow of all information that travels through the CMS according to the functional diagram.

Figure 8 : CMS SV-4 Data Flow
Operational Need

- All buses need internet connectivity to access information from control center
- All buses will need to be equipped with monitors to view routes
- All bus drivers will need a mode of communication (voice over IP) to communicate with the control center
- All buses will need to be mechanically tuned and filled with gas

Figure 9: CMS Buses
A device to take a poll of the direction bus passengers desire to travel along the train metro.

The control center needs a working server that can handle and process the algorithm.

The control center needs employees of the High Commission for the Development of Arriyadh manning the control system.
The streets need functional and operating sensors to detect the congestion state of the streets.

The Train Metro needs functional and operating Infrared cameras and facial recognition algorithms at the stations.
Operational Scenarios

Operational Scenario 1

Operational Scenario 2
X = Traffic waiting time  
Y = Station waiting time  
Z = Time between A + B

**Total Wasted Time:**

Go to A: 
\[
\left( X_A + Y_A + Z \right) - \left( X_B + Y_B \right) \text{ min } \times 20 \text{ ppl} \\
\left( 10 + 10 + 10 \right) - \left( 10 + 10 \right) \text{ min } \times 20 \text{ ppl} \\
\left[ 30 - 20 \right] \text{ min } \times 20 \text{ ppl} \\
10 \text{ min } \times 20 \text{ ppl} = 200 \text{ min for 20 ppl}
\]

Go to B: 
\[
\left( X_B + Y_B + Z \right) - \left( X_A + Y_A \right) \text{ min } \times 40 \text{ ppl} \\
\left( 10 + 10 + 10 \right) - \left( 10 + 10 \right) \text{ min } \times 40 \text{ ppl} \\
\left[ 30 - 20 \right] \text{ min } \times 40 \text{ ppl} \\
10 \text{ min } \times 40 \text{ ppl} = 400 \text{ min for 40 ppl}
\]

**Going to A < Going to B**, meaning total time wasted is less going to Station A.

*Therefore the bus should go to Station A.*

**Figure 14: Operational Scenario 1**
Total Wasted Time:

Go to A:

\[
\left( X_a + Y_a + Z \right) - \left( X_b + Y_b \right) \text{ min} \times 20 \text{ ppl} \\
\left( 20 + 20 + 10 \right) - \left( 10 + 10 \right) \text{ min} \times 20 \text{ ppl} \\
\left( 50 - 20 \right) \text{ min} \times 20 \text{ ppl} \\
30 \text{ min} \times 20 \text{ ppl} = 600 \text{ min for ppl}
\]

Go to B:

\[
\left( X_a + Y_a + Z \right) - \left( X_b + Y_b \right) \text{ min} \times 40 \text{ ppl} \\
\left( 10 + 10 + 10 \right) - \left( 20 + 20 \right) \text{ min} \times 40 \text{ ppl} \\
\left( 30 - 40 \right) \text{ min} \times 40 \text{ ppl} \\n-10 \times 40 \text{ ppl} = -400 \text{ min for 40 people}
\]

Going to A > Going to B, meaning total time wasted is less going to Station B.

*Therefore the bus should go to Station B*
Figure 16: OV-4 Congestion Management System
Figure 17 is the activity diagram of the CMS in relation with a passenger. At the beginning the CMS takes the poll of which direction the passenger intends to travel along the train route, and once it reaches the calculation point (CP) it initiates the algorithm to determine the station to route to. The decision is then displayed on the bus driver's display indicating to which station the driver shall drive to, and finally all passengers are dropped off at the designated station.
Risk Management

Risk management is the identification and control of risks during all phases of the project life cycle.

Risk is an event that, if it occurs, adversely affects the ability of a project to achieve its outcome objectives.
<table>
<thead>
<tr>
<th>No.</th>
<th>Risk</th>
<th>Likelihood</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The High Commission for the Development of Riyadh will not accept my proposed system</td>
<td>3</td>
<td>4</td>
<td>Contingent upon the reason for rejection, adjustments and alterations to the proposed system can be made for resubmittal</td>
</tr>
<tr>
<td>2</td>
<td>Citizen Reception of System</td>
<td>3</td>
<td>3</td>
<td>Work with government to change image</td>
</tr>
<tr>
<td>3</td>
<td>Human Error</td>
<td>1</td>
<td>3</td>
<td>Re-train or terminate employee</td>
</tr>
<tr>
<td>4</td>
<td>Traffic congestion on Roads</td>
<td>1</td>
<td>2</td>
<td>Ask Control Center for alternative route</td>
</tr>
<tr>
<td>5</td>
<td>Network Failure</td>
<td>3</td>
<td>1</td>
<td>Use other mode of communication to get information from Control Center</td>
</tr>
<tr>
<td>6</td>
<td>Breakdown of equipment: Infrared Camera in Train Station</td>
<td>1</td>
<td>1</td>
<td>Replace or fix Infrared Camera</td>
</tr>
<tr>
<td>7</td>
<td>Algorithm Failure (Software Bug)</td>
<td>3</td>
<td>3</td>
<td>Debug and re-test algorithm</td>
</tr>
<tr>
<td>8</td>
<td>Breakdown of equipment: Camera used for Facial Recognition</td>
<td>1</td>
<td>2</td>
<td>Replace or fix camera</td>
</tr>
<tr>
<td>9</td>
<td>Breakdown of equipment: Monitor on Bus</td>
<td>5</td>
<td>3</td>
<td>Replace or fix monitor</td>
</tr>
<tr>
<td>10</td>
<td>Breakdown of equipment: Monitor at Control Center</td>
<td>1</td>
<td>4</td>
<td>Replace or fix monitor</td>
</tr>
<tr>
<td>11</td>
<td>Breakdown of equipment: Bus Mechanical Failure</td>
<td>3</td>
<td>5</td>
<td>Replace or fix bus</td>
</tr>
<tr>
<td>12</td>
<td>Network Hacking/Virus</td>
<td>1</td>
<td>5</td>
<td>Reconsider IT solutions</td>
</tr>
</tbody>
</table>

Table (1): List of Risks
Figure 18: Risk Assessment Matrix
Ethical and Social Issues

- Handicap Passengers
- Air Pollution
- Small Bus Driver
Handicap Passengers

Saudi Arabia does offer some services and protection for those with disabilities but “there is no legislation prohibiting discrimination against disabled people or overseeing the provision of access”. The buses are expected to have means to accommodate handicapped citizens and naturally a way for them to access the metro train system as well.

Air Pollution

According to the United Nations, Riyadh is one of the most polluted cities in the world next to Beijing and Mexico City. Already with such a reputation, the addition of hundreds of buses to the streets of Riyadh will only make it worst. Unless there are measures to either alleviate the pollution the buses will contribute or to discover alternatives ways to power the buses, the situation of pollution will worsen in no time in Riyadh.
Social Issues of Small Bus Drivers

The introduction of these buses that are intended to transport passengers from their homes to the train stations will take away a lot of the revenue from small bus drivers (similar to taxis) that would otherwise be generated if not for these large transporter buses. This gives rise to the social issue of causing a great reduction in availability of jobs as a small bus driver. Some of these drivers rely on this revenue and income to support their families; this new transport bus system can detrimentally affect their way of living. A similar situation is occurring in many cities now in the US due to the increased use of Uber over conventional taxis.
Lean thinking is defined to be a process where the system engineer "is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value added wastes."
Six Principles That Lean Thinking Uses

- Values
- Value Streams
- Flow
- Pull
- Perfection
- Respect People
How lean thinking applies to the CMS:

- **Value:**
The value of the CMS is a service of transporting passengers of the train system to their respective train station destinations as quickly and functionally possible.

- **Value Stream & Value Flow:**
  - The value stream of the system starts with picking up the passengers at bus stops, transporting them to their desired location, and dropping them off at the most appropriate station.
  
  - The algorithm used to avoid the congestion at any given station demonstrates the optimization of a value stream and thereby flow because it helps the system avoid unnecessary wait time for the passengers, allowing for the continuous flow of passengers in the train system.

- The careful scheduling of bus drivers also optimizes the value stream and therefore the value flow because it ensures that there are no bus drivers that are not picking up or dropping off passengers.
- Pull:
  Currently there is no plan for a direct pull from customers but when there is a surge of customers thereby causing there to be wait time at a train station, there is an indirect pull that triggers buses to redirect traffic of passengers to other train stations.

- Perfection:
  When all aspects of value stream runs seamlessly we should see that the system should operate at a level of perfection where the flow of passengers from location to location is executed smoothly.

- Respect for People Principle:
  Albeit minimal communication between many of those operating the system, as mentioned earlier good managers who are good at keeping the efforts of the system's operators together and consistent will significantly reduce the risk of any miscommunication when required, ie) communication between the bus drivers and the control room.

- Each subsystem including the road monitoring system, facial recognition system, bus system, server system, and control room system, shall implement frequent improvement cycles for each process according to a predetermined strategy deployment.
Start

- Travel time to Bus Station \( T_1 \) min
- Wait time at bus station \( T_2 \) min
- Bus ride time to CP \( T_3 \) min
- Bus ride time to predetermined station \( T_4 \) min
- Waiting in train Station \( T_6 \) min

Minimum total time
\[ = T_1 + T_2 + T_3 + T_4 + T_6 \] min

Board train

Figure 19: Before Lean Thinking
Start

Travel time to Bus Station  
T1 min

Wait time at bus station  
T2 min

Bus ride time to CP  
T3 min

Bus ride time to algorithm determined station  
T5 min

Waiting in train Station  
T7 min

Board train

Minimum total time  
= T1 + T2 + T3 + T5 + T7 min  
(T5 + T7 < T4 + T6)

Figure 20: After Lean Thinking
Implementation Methods

The first most important information would be to determine what the best routes for all buses would be. This would first require extensive knowledge of the city's transportation infrastructure and traffic engineering to understand how much an area's traffic is impacted by the new traffic introduced by buses. After this is determined a comprehensive test should follow to verify and test the hypothesis. After such tests have been conducted, schedules for the buses can be set accordingly to limit the amount of wasted time.

Improvement Summary

<table>
<thead>
<tr>
<th>ITEM</th>
<th>PLANNED SYSTEM</th>
<th>CONGESTION MANAGEMENT SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery time</td>
<td>T1+T2+T3+T4+T6 min</td>
<td>T1+T2+T3+T5+T7 min</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Satisfactory</td>
<td>Good</td>
</tr>
<tr>
<td>System Safety</td>
<td>Satisfactory</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Verification and Validation Methods

Figure 21 is a context diagram that shows a high level description how the CMS relates with the stakeholders as well as how it satisfies the requirements but is limited by its constraints. This diagram will be used to verify some of the requirements of the CMS.
1. Buses must be able to connect to the system server and control center.

   **Verification:** Demonstration - also known as "field testing", this method is used to demonstrate correct operation without physical measurements. The requirement is verified when the bus can demonstrate that it is able to connect to the system server and control center through a variety of short demonstrations that show the connectivity such as bus drivers having a quick conversation with control center operators.

2. Passenger must be able to input the destination direction.

   **Verification:** Inspection - a technique based on visual examination relying on the human senses and/or using simple methods of measurement and handling. The requirement is verified when an inspector touches the touch panel to indicate either an 'up' or 'down' direction and the system recognizes the input and displays it on the bus monitor.
Facial Recognition and traffic monitoring system must regularly update the system server.

Verification: Inspection - this technique again applies here because an inspector can verify that the system server is constantly being updated with new data. A temporary or fixed camera can be implemented to ensure that the information being feed to the server reflects what is being seen on the camera feed.

The algorithm must decide on the path that wastes the least ar time among the bus passengers.

Verification: Analysis - a technique based on analytical evidence based on math or probability that follows logical reasoning. The requirement is verified when the result of the executed algorithm outputs the appropriate bus route decision based on the math designated earlier in the project under operational scenarios.
Validation

The system is validated when the Ministry of Transportation examines the specifications and design choices made for this system and approves for use in their new metro train station system. This means they believe the system performs in a way to enhance their proposed system and that it is valuable because it adds value to their system.
Lessons Learned

There is much to be said from what I have learned from working on this project, but one of the most valuable lessons I have learned is asking good questions about why certain systems that exist already are done the way they are done. Specifically, after much thought I have put into thinking about the algorithm to decide which station is better for the passengers, I now understand why bus systems all over the world have a common way in running the system. Before, it never occurred to me why buses ran their schedules the way they did, but after varying my bus system and changing several features and trying different algorithms, I have learned that the proposed bus system is one of the best ways to approach the situation. Yet, I have also learned not to be discouraged by convention and to challenge the norm by introducing what seems to be a unconventional and unique way of running bus systems. The algorithm uses good math to support its decision making logic. I have a desire to make this algorithm even more effective for future improvements of this system.
Conclusion

- The CMS is another step towards improving the lives of Riyadhians.

- The intent of CMS is to add value to the bus systems intended to accompany and assist the passenger routing to the train system.

- The algorithm is meant to reduce the collective time wasted by all passengers of the bus by accounting for the bus travel time and waiting time at train stations.

- The system is a simple but positive step in the direction of automating and making the bus system smarter.

- The system can further be explored to add other features or a better algorithm that would help enhance the upcoming installment of the Riyadh Metro Train System.
List of Figures and Tables

Figure 1: Riyadh City Map
Figure 2: Riyadh Densely populated area
Figure 3: Riyadh Traffic
Figure 4: Riyadh Freeway Traffic
Figure 5: Bus Route for Planned System
Figure 6: OV-1 High-level View of Congestion Management System
Figure 7: CMS SV-4 Functional Diagram
Figure 8: CMS SV-4 Data Flow Diagram
Figure 9: CSM Buses
Figure 10: CMS Main Train Stations
Figure 11: CMS Sub Train Stations
Figure 12: CMS Control Center
Figure 13: CMS Operation offices
Figure 14: Operational Scenario 1
Figure 15: Operational Scenario 2
Figure 16: OV-1 Detailed-View of Congestion Management System
Figure 17: CMS OV-5 Activity Diagram
Figure 18: Risk Assessment Matrix
Figure 19: Before Lean Thinking
Figure 20: After Lean Thinking
Figure 21: CMS Context Diagram

Table (1): Risk Management
Table (2): The Improvement Summary table
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