Traffic Control System

A comprehensive Software Development Life Cycle report

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# Introduction

The aim of the project is to build a Traffic Control System (TCS) for Dublin City Council (DCC). The TCS falls within the remit of Safety Critical Systems because of which utmost care should be taken during the entire life cycle of the project development.

The team developing the project consists of four developers of which two are senior developers. One of the senior developers has prior experience working in Aircraft Control Systems which is a heavily regulated industry very much similar to the TCS. This team is managed by a Project Manager with considerable experience managing Software Development Projects and also a Scrum Master. The team works for a firm which has over three and a half decades of experience developing software systems using various process models such as Agile, Plan Driven and Hybrid models. All this valuable experience of the team and the firm will play a critical role in the software development of this Safety Critical System.

# SDLC

The Chaos Report (2015) shows that only 29% of Software Projects are completed successfully. The large number of failed projects forms a major concern for any software development firm or a customer who requires services from the software industry (Hastie, 2015).

In order to be able to deal with such uncertainties, almost all major software development firms adopt SDLC - Software Development Life Cycle.

Software Development Life Cycle is the process of designing, developing and testing high quality software. It encompasses the entire journey of a software from the idea of it to deploying and maintaining it. The SDLC is divided into various stages. Each stage focuses on a very critical element of the journey. Together, this cycle makes sure that the project is completed successfully to the user expectations, within the budget and delivered on time (*SDLC - Overview - Tutorialspoint*, no date).

## Process Model

The SDLC is generally based on the framework of a Process Model. There are various Process Models each with its own advantages and disadvantages. The DCC prefers the Waterfall Model as this model enables greater control by the management and can also be tracked easily as it moves from one stage to the other. The project is only advanced to the next stage when all the goals of the previous stage are achieved and signed off. The flow is linear hence it is also called as the ‘Linear Sequential Model’.

The software firm has experience working with multiple different process models like Agile, Plan Driven and Hybrid Model. For the TCS project, the firm will be using the Hybrid Model based on the paper published by Munassar and Govardhan in 2010. This specific Hybrid Model takes the advantage of the below list of Process Models and integrates it into one:

* Waterfall Model
* Iteration Model
* V-Shaped Model
* Spiral Model
* Extreme Model

The flow of the Hybrid Model can be shown as below:

A screenshot of a cell phone

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*Fig. 1 – Hybrid Process Model (Munassar and Govardhan, 2010)*

This model is structured similar to the Waterfall Model in the way it is linear and sequential with each stage differentiated clearly. Along with the set goals for each stage, emphasis is also placed on risk analysis and testing from the first stage itself. This helps address one of the biggest draw-back of the Waterfall model.

This Hybrid Model will give the TCS project the following advantages:

1. Specific milestones for each stage
2. Deliverables for each stage
3. Higher chance of success as the test plans are developed early on in the life cycle
4. High amount of risk analysis
5. Good for safety critical projects
6. Test based approach to gathering requirements and ensuring quality

(Munassar and Govardhan, 2010)

These advantages play a crucial role when it comes to designing and developing a safety critical system such as the TCS. Moreover, as the Hybrid Model is primarily structured around the Waterfall Model itself with the added bonus of various other models too like Risk Analysis and Testing phases, it will be easier to convince DCC to come on board with this software development approach.

The TCS project will be driven with the understanding of SDLC based on the Hybrid Process Model Framework. It will be divided into the following six stages:

* Requirements
* Design
* Implementation
* Integration Development
* Deployment
* Maintenance

# Requirements

Requirements gathering is the first stage in any kind of Software Development. Capers Jones Study shows the stages where software projects tend to fail. Of this, 12.50% was because of Requirement errors (Jones, 1986). This is an alarming number considering the fact that gathering and analyzing requirements is the very first step towards developing the software. This means, 12.50% of the projects were faulty from the very beginning even before the developers put in their first line of code. To overcome this in our TCS project, the process of gathering requirements should be considered just as important if not even more than the designing or coding stage.

## Stakeholders

Stakeholders include anyone who will be affected by the project or affect the outcome of the project. They could be internal or external stakeholders (‘Software Engineering | Stakeholder’, 2019). Stakeholders for the TCS include the government - DCC, pedestrians, emergency services, the software development firm and the development team – project manager and developers.

## Types of Requirement

There are two types of Requirements, Functional and Non-functional Requirements.

Functional Requirements are specifications of the TCS system detailing what it should do in a particular situation like, when an emergency vehicle is approaching or on getting certain input like when pedestrians click on the button to cross the road.

Non-functional requirements, on the other hand, talk about how the TCS should behave. It refers to the constraints placed on it like audio feedback when the pedestrian button is pressed, the height of the traffic poles, the brightness of the LED’s used, etc.

## Requirements Engineering Processes

To standardize the process of gathering requirements and to overcome the communication gap between the various stakeholders of this project, four activities shall be defined. They are:

* Elicitation
* Analysis
* Validation
* Management

## Elicitation

The first activity is the process of requirements elicitation or discovery. The Project Manager along with a Senior Developer shall discuss with the customer, DCC in this case, extensively regarding the services the system should provide and its operational constraints. Elicitation is further broken down into:

* Requirements Discovery
* Requirements Classification and Organization
* Requirements Prioritization and Negotiation
* Requirements Specification

The requirements for TCS are gathered and documented through interviews and scenarios (refer Appendix 1) during the Requirements Discovery level. Requirements can also be discovered in the form of User Stories.

## User Stories

User Stories are short descriptions of the requirements of the system. They are usually given from the perspective of an end user of the system but in general can be written by anyone. Focus here is on the discussion of the stories itself rather than who has written it or what is written. User stories act as a pointer to the real requirements of the system and should ideally connect to some kind of artifact (Cohn, no date).

For the TCS project, the functional and non-functional requirements written in the form of user stories are:

1. As part of the DCC Traffic Control Unit, we want the TCS to manage the traffic automatically so that traffic congestions can be avoided. (Functional)
2. As a Traffic Control Operator, I want the TCS to also have manual signal delay adjustments so that I can override during special circumstances. (Functional)
3. As an ambulance driver, I want the TCS to automatically clear the traffic so that I can reach my destinations quickly and save lives. (Functional)
4. As a pedestrian, I want the TCS to enable me to stop the flow of traffic so that I can cross the road safely. (Functional)
5. As a pedestrian, I want the traffic signal to have a countdown timer so that I can know beforehand if I have enough time to cross the road. (Functional)
6. As part of DCC Traffic Control Unit, we want the road sensors and traffic camera data to be stored in Dublin Central Traffic Control Database within DCC’s secure datacenter so that it is safe for privacy and security reasons. (Functional)
7. As the Dublin Central Traffic Control Database, we want M programing language to be used so that MUMPS database system can be used. (Functional)
8. As part of DCC, we want the sensor data to be timestamped so that it adheres to legal requirements. (Functional)
9. As the DCC Traffic Control Unit, we want the programming language to be C/C++ so that the sensor array of 16K or 32K can be used efficiently. (Functional)
10. As a person with disability, I want the pedestrian button to be big and low so that it is easily accessible. (Non-Functional)
11. Reliability – As a Traffic Control Operator, I want the TCS to be reliable enough so that it doesn’t crash unexpectedly. (Non-Functional)
12. Security – As part of the DCC, we want the TCS to be secure and encrypted so that it is safe from unauthorized access. (Non-Functional)
13. Maintainability – As part of the DCC, we want the TCS to be updated periodically so that the system stays up to date and free of bugs. (Non-Functional)

The next level is to organize these requirements into relevant groups such as:

* Safety Critical Systems requirements
* Pedestrian requirements
* Emergency vehicles requirements
* Programming language requirements
* Hardware requirements
* Database management requirement
* Legal requirements
* Infrastructure requirements
* Budget requirements

This is followed by prioritizing the requirements like how EVAS will take higher priority than pedestrians or regular traffic and resolving any conflicts.

Finally, in the Requirement Specification stage, the requirements are documented in two categories:

* User Requirements
* System Requirements

User Requirements are those focused on end users like DCC and general public. These do not include any technical information. Whereas, the System Requirements are targeted towards the developers and as such contain technical jargons. These are more detailed than the User Requirements.

## Requirement Specification

Requirement Specification is the process of documenting the user requirements and system requirements. They can be done in two ways:

* Natural language Specification
* Structured Language Specification

The following are the Functional Requirements of the TCS written in structured language:

|  |  |
| --- | --- |
|  | Traffic Control System/Signal Interval Logic/SRS/1.1 |
| Function | Calculate signal change frequency |
| Description | Calculates the time interval between changing signals for each lane based on flow of traffic |
| Inputs | Road sensors and traffic cameras |
| Processing | Calculate traffic density based on the inputs and process them using the SCOOT algorithm (Skabardonis *et al.*, 2013) to decide the signal change frequency |
| Outputs | Change in the interval between signal changes |
| Pre-Condition | The TCS sensor data and video data are relayed to the processor continuously |
| Post-Condition | Post analysis, the wait time reduces during low traffic and increases during high traffic |

*Table 1 – SRS for Signal Interval*

|  |  |
| --- | --- |
|  | Traffic Control System/EVAS Override/SRS/1.2 |
| Function | Clear traffic for emergency vehicles |
| Description | The TCS prioritizes approaching emergency vehicles and clears traffic ahead of it |
| Inputs | Data from EVAS |
| Processing | Determine the direction an emergency vehicle is approaching and override all the traffic signals along that path to keep the traffic to a minimum |
| Outputs | Signals change to green in the lane an emergency vehicle is approaching |
| Pre-Condition | TCS synced with EVAS |
| Post-Condition | Once the emergency vehicle passes, the TCS operations resume to normal state and the override is removed |

*Table 2 – SRS for EVAS Behavior*

|  |  |
| --- | --- |
|  | Traffic Control System/Pedestrian Control/SRS/1.3 |
| Function | Stop traffic to enable pedestrian to cross the road |
| Description | When a pedestrian presses the traffic button, the TCS will need to determine when to stop the traffic flow so that the pedestrian can cross the road safely |
| Inputs | Data from pedestrian button |
| Processing | On receiving a signal from the pedestrian button, the TCS will calculate based on the traffic density when to change the lane to red and pedestrian to green |
| Outputs | Lane signal turns red and pedestrian signal turns green |
| Pre-Condition | The EVAS should not have overridden the TCS |
| Post-Condition | After a fixed time, interval changes the pedestrian signal to red and resume normal flow of traffic |

*Table 3 – SRS for Pedestrian Control*

The following are the Functional Requirements Specification of the TCS written in natural language:

2.1 The TCS shall store the traffic data from the road sensors and traffic cameras in MUMPS database by using M language so that it can be stored safely in DCC’s secure data center.

2.2 The TCS shall timestamp all the data collected in order to abide by the legal regulations.

3.1 The road sensors shall be programmed in C/C++ so that the array memories between 16K and 32K size can be used.

## Analysis

Requirement analysis is the stage where the software team determines if the stated requirements for the TCS are incomplete, ambiguous or contradictory. If any are identified, then these are clarified before proceeding further (*Requirement Analysis Techniques*, no date).

## Validation

Validation forms a crucial part of the Requirements Engineering Process. This stage is used to confirm that the TCS requirements gathered so far and analyzed is what DCC actually wants. If the project is delivered without passing through the validation stage and it contained any kind or requirement errors, then the cost of fixing this may be 100 times more than fixing any implementation errors (Sommerville, 2016). Validation is done by checking the following parameters of the TCS:

* Consistency
* Completeness
* Realism
* Verifiability
* Validity

The requirements of the TCS are validated through requirement reviews which is a systemic manual analysis of the requirements. The reviews will include both the software development team and DCC.

## Management

Changes in requirements will need to be accommodated into the process throughout the SDLC. Changes initiated during the early stages of the SDLC are always easier to implement than those which come up towards the end. This is where Requirements Management plays a crucial role. By having a set of procedures to tackle changes in requirement will make it easier to implement the changes.

The software development team will keep a track of all the requirements put forward by DCC and its dependencies. This will help understand the relationships between the various requirements and processes. In case DCC updates their requirements or modifies any existing ones during the course of the SDLC, then the team will be able to assess the cost estimate and impact easily.

In whole, the requirements gathered will help get a clear understanding of the system to be developed and what is expected out of it before we start to build it.

# Design

Once the software requirements specifications document for the TCS is verified with the DCC and approved, the team will move to the design phase. The design stage uses the inputs from the SRS documents to design the software architecture of the TCS. The figure 2 shows the overview of the TCS architecture.

TCS Design Architecture
Description automatically generated

*Fig. 2 – TCS Design Architecture*

The figure 2 shows a centralized TCS. Data from various sources are processed and the traffic managed based on the SCOOT algorithm. The entire system can be monitored from the Traffic Control Room with live traffic data flowing in. The control room has access to manually override the TCS if needed. They can also access historical traffic data from the database by providing valid credentials. All the traffic data collected is time stamped and stored within the DCC’s Data Center directly from the sensors. This will avoid any kind of tampering with the data. The EVAS is given the highest interrupt priority so that the TCS prioritizes them before other sources.

## UML – Class Diagram

The class diagram is used to represent the attributes or classes of a system. Each class also shows the various methods used within it. The TCS comprises of the attributes like the ‘DCC Traffic Control’, ‘Permissions’, ‘Routes’, ‘Diversions’ among others.

A close up of text on a white background

Description automatically generated

*Fig. 3 – Class Diagram (refer Appendix 2 for UML diagram link)*

Figure 3 shows all the classes used in the TCS and their associations with each other. The Dublin Central Traffic Control class consists of the attributes like the Traffic Controller ID, name, description and its password. This class has methods which enable to add, edit, delete or search for a traffic controller in the system. The access to this class is managed by the Permissions class. The Permissions class manages methods which can add, edit, delete or search for users with permissions access. Each user is given an ID based on their role for managing permissions. This is done with the use of Role class. A new user is registered into the system by the User class. This class collects the user’s information to be stored in the database. All these classes together manage the user end of the TCS.

The next set of classes is used to manage the traffic parameters. These include the Routes, Traffic, Length and Diversion classes. The Routes class manages all the route maps of the TCS. Traffic class manages the real time traffic data collected from the sensors and cameras. The Length class manages the duration of the traffic signal depending on the flow of the traffic across all the routes. Finally, the Diversions class can be used to manage diversions in traffic based on which the flow of the traffic can be adjusted.

## UML – Use Case Diagram

The Use Case diagram shows how different types of users can access the TCS. There are primarily two types of users: admin and controller. Each kind of user has their own sets of permissions associated within the system. The admin is the top-level user who can mange everything including adding new controllers to the system, managing traffic routes and diversions. The controller on the other hand has limited access to the system like managing signal timings and searching the routes to view the density of the traffic. This is shown in figure 4.

A close up of a map

Description automatically generated

*Fig. 4 – Use Case Diagram (refer Appendix 2 for UML diagram link)*

## UML – Activity Diagram

The Activity diagram shows the flow of various activities within the system. The flow can be sequential, branched or concurrent. The figure 5 shows the Activity diagram for the TCS.

A close up of text on a white background

Description automatically generated

*Fig. 5 – Activity Diagram (refer Appendix 2 for UML diagram link)*

The activity diagram uses swim lane approach with all the actors in different lanes. The TCS lane is the central aspect to the entire system. It collects inputs from EVAS, pedestrian control, road sensors and DCC control room. The TCS system receives three levels of interrupt signal codes. The normal traffic management is given the least priority which is the default state of the system indicated in the ‘Normal Traffic Management State’ block. The pedestrian block gets medium priority. Whenever a pedestrian presses the button, a medium interrupt signal is sent to the TCS. This starts the countdown timer for the pedestrians to cross the road. Once the timer expires, the pedestrian system is set back to the idle state. Finally, the EVAS system is given the highest interrupt priority. This is managed by the emergency services directly and can override the TCS. As long as the EVAS alert signal is active, the TCS control is overridden by EVAS system. Once the alert is cleared, the EVAS gets back to standby state allowing the TCS to return to normal functionality.

The DCC Control Room has the access to the TCS system directly in case manual control is required. This requires special access and authorizations through a login page. They can access the DCC Data center which stores the timestamped traffic data from the sensors.

## UML – Sequence Diagram

The Sequence diagram is an interaction diagram which shows the interactive behavior of the system in a sequential order. Figure 6 shows the Sequence Diagram of the TCS.

A close up of a map

Description automatically generated

*Fig. 6 – Sequence Diagram (refer Appendix 2 for UML diagram link)*

The Sequence diagram shows how the Admin accesses the system. He is first taken to the login page. On successfully logging in the admin is verified across the DCC database. Based on the admin privileges, a session is created for the user. In case the user is unable to login to the system the they will be directed to the forgot password page where they will need to answer the security question. On successfully validating the security questions, an email will be sent to reset the password.

## Justification

# Test Cases

A Test Plan is used to test the TCS in various scenarios. These test cases help analyze the performance of the TCS before it is implemented. This helps provide a glimpse into the functionality of the system in live conditions. The table 4 shows five different test case scenarios for the TCS.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No** | **Test Case** | **Scenario** | **Expected Result** | **End Result** | **Status** |
| 1 | EVAS | The system will detect the approaching emergency vehicle and would instantly change the light to green, or it can show a separate indicator light for the emergency vehicle to pass. | The red traffic signal needs to change to green as the emergency vehicle approaches. | The red signal changed to green. | Pass |
| 2 | Signal change | Lanes with higher traffic density are set to green longer while the other lanes are in red for that duration. | Green signal for the most congested path needs to remain on.  The signals on the other two opposite lanes need to be red to stop the flow of traffic. | The lights remained red for two opposite lanes and green for the other two opposite lanes. | Pass |
| 3 | Timing variation | The time for which the signal remains red or green varies with the level of congestion and flow of traffic on the roads. | The time for which the light remains green in the busy path needs to be increased and reduced again when the flow reduces. | The green light remained on for the set duration when the flow of the traffic increased and then subsequently decreased to the minimum duration when the number of vehicles reduced. | Pass |
| 4 | Displaying countdown | The countdown will be displayed whenever the signal goes red. | As the red light turns on, the countdown for crossing the road also needs to start. | The light changed from green to red and the countdown display started. | Pass |
| 5 | Displaying Error Message | The user of the TCS will get the error message when the user fails to authenticate. | Error needs to be filed and message to be displayed when the user puts the wrong password. | Error Message displayed when the user entered the wrong password. | Pass |
| 6 | Interrupt Priority Test | The TCS will receive all the interrupt signals (EVAS, Pedestrian and High Traffic) simultaneously. | TCS should prioritize them based on the interrupt levels from high to low. | The TCS prioritized EVAS first. After the vehicle passed, normal working resumed. This was followed by the pedestrian interrupt. Finally, the lanes with high traffic were kept in green for longer. | Pass |

*Table 4 – Test Cases*

# Risk Analysis

|  |  |  |
| --- | --- | --- |
| **Risks** | **Details** | **Mitigation** |
| Technical Risks | The system may fail to operate.  The system may not be able to communicate with the other field elements.  The data transmission may get interrupted.  The monitoring system can fail due to server problems.  The lights may become inoperative.  The timing delay may be wrongly programmed, which can lead to false phase detection. | The admin needs to check the system periodically to identify any faults. The admin should also incorporate proper maintenance of the system.  Cloud computing encryption features should be included to enable safer communication system within the field elements.  The lights and the electrical system should be periodically checked.  The programming should be checked and tested before deployment to avoid this. |
| Security Risks | The TCS could be hacked due to security breaches. | Ensuring the credentials of the users are monitored closely. |
| Operational Risks | Operational risk may arise when there is involvement of multiple parties handling TCS.  The operator may not be trained to handle TCS. | The operation of the TCS should be centralized to avoid any conflicts.  The operator should be trained for the correct implementation and operation of the TCS. |

*Table 5 – Risk Analysis*

# First Release Plan

The planning for the project launch will include taking into account the pre-requisites for the task. These include sharing information with the stakeholders of the project. The resources that are available for the project should also be identified, when including data and charts.

The first Release plan for the software will be aimed at addressing the project objectives and checking whether the system can perform its designated functional and non-functional tasks. The steps that will be taken for this review is as provided below:

**Product Vision:** To demonstrate the working of TCS and its corresponding functional and non-functional requirements.

**Release Schedule Review:** The schedule for the release will be decided based on the outcomes of the test case scenarios and risk case analysis by all the stakeholders.

**Plan Schedule:** The different milestones within each stage of the project will be identified and the corresponding data be presented regarding its functionality progress. Based on this data a schedule will be planned for the next stages.

**Map the expected User story scenarios to Test Results:** From the user stories collected so far, the functional and non-functional requirements will be mapped to the results obtained for ease of tracking.

**Communication Plan:** The communication plan will help maintain a clear and consistent channel between all the stakeholders during the development of the TCS. This will enable the DCC to provide the team with any changes in their requirements if any are felt necessary. These can then be implemented prior to releasing the final product. The first release should have a log of all these communications with their status in the project.

**Test Case:** The functionality of the TCS is demonstrated to the DCC through various test case scenarios. The scenarios will try to address the functional and non-functional requirements.

**Re-Release:** Schedule for future releases, if any.

# Code

The software team has developed the code for the working of the TCS. The code shows how the system changes the traffic signals between the lanes (refer Appendix 3).

# Conclusion

Once the TCS project achieves all the milestones for each of the stages post the first release, it will be time to deploy the project on large scale. As the infrastructure is being laid out by the DCC, the team will be working on setting up the DCC Traffic Control center and configuring their systems. The User Manual of the system will be handed over once all this is complete. The manual will contain every single detail of the TCS, UML diagrams, EVAS integration, troubleshooting scenarios, hardware specification and configuration details and so on.

# Appendix 1

1. What is the project?

To build a Traffic Control System, TCS, for Dublin City Council, DCC.

1. What is required of the TCS?

The system must access and use data from road sensors and traffic cameras that indicate the flow of vehicular traffic and the extent of congestion in order to determine optimal light changes alongside pedestrian users’ requirements too.

1. What are the specifications of the road sensors?

The sensor arrays have between 16K and 32K of memory.

1. Is there any requirement for the programming language used?

The system should use either C or C++ as the programming language.

1. Where is this data stored?

All sensor data and video data must be collected and stored in the Dublin Central Traffic Control Database which is located in DCC’s secure data centre.

1. What is the database used to store this data?

The data must be stored in the MUMPS database system. This should be written in the M language, hosted on Linux and timestamped for legal reasons.

1. Are there any other specific requirements expected of the TCS?

The TCS should come within the remit of safety critical systems. The system should also interface with the Emergency Vehicle Approach System, EVAS.

1. How exactly do you see this working? Could you give a scenario?

When any emergency vehicle is approaching then the TCS should override traffic signal controls to prevent traffic flow ahead of the approaching emergency vehicles (fire engines, ambulance, police and/or security forces). The EVAS signal change requests require priority processing ahead of pedestrian traffic light button presses.

1. Do you have any preferences in process model?

Yes. Waterfall software development model.

# Appendix 2

GitHub repository link for UML diagrams:

<https://github.com/srikanthshileshpasam/SE_CA1_B9IS119.git>

# Appendix 3

#include

void Delay(int); // Delay Routine

void SupDelay(int); // Delay Routine

void main()

{

PINSEL2 = 0X00000000; // P1.24 TO P1.31 as GPIO

IO0DIR = 0X0000FFF0; // P1.24 TO P1.31 Configured as Output port

while(1)

{

IO0SET = 0x00003090; // D19 GREEN, ALL RED

Delay(500);

IO0CLR = 0x00001000;

IO0SET = 0x00002890;

SupDelay(100);

IO0CLR = 0x000002890;

Delay(1);

IO0SET = 0x00008490; // D22 GREEN, ALL RED

Delay(500);

IO0CLR = 0x00008000;

IO0SET = 0x00004490;

SupDelay(100);

IO0CLR = 0x00004490;

Delay(1);

IO0SET = 0x000024C0; // D13 GREEN, ALL RED

Delay(500);

IO0CLR = 0x00000040;

IO0SET = 0x000024A0;

SupDelay(100);

IO0CLR = 0x000024A0;

Delay(1);

IO0SET = 0x00002610; // D16 GREEN, ALLRED

Delay(500);

IO0CLR = 0x00000200;

IO0SET = 0x00002510;

SupDelay(100);

IO0CLR = 0x00002510;

Delay(1);

}

}

void Delay(int n)

{

int p, q;

for(p=0; p<n; p++)

{

for(q=0; q<0xFFF0; q++);

}

}

void SupDelay(int n)

{

int p, q;

for(p=0; p<n; p++)

{

for(q=0; q<0xFFF0; q++);

for(q=0; q<0xFFF0; q++);

}

}

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