UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
School of Electrical and Information Engineering
SD Methodologies, Analysis and Design

Course Project — Road Network Maintenance

1 Introduction

The maintenance of a city's road network is crucial in order to support the economic growth of the city and its citizens. Road network maintenance is often the responsibility of local government. The task for this project is to design and prototype a system which aid the transport department of local government in maintaining their assets, which in include not only the road network but also supporting infrastructure. Specifically, the system will be used for identifying, monitoring, and managing the resolution of faults identified with this infrastructure. Faults include potholes, broken traffic lights, blocked road-side drains, damaged kerbs, worn road markings, missing signage, and so on. An integral part of the system is a mobile component for use by the field staff so that faults can be captured and recorded on-site.

2 Fault Logging

Members of the public can call in to log faults that they may have discovered or encountered. A call-centre operator will use this system to capture faults (type, address, GPS coordinate, description and call-centre priority). One of the challenges is that the operator must communicate with the caller to determine the precise location of the fault. Often the addresses supplied are incomplete and callers do not have GPS coordinates.

A street address can be used to determine the approximate location (geocode) of the fault. The system should provide the operator with the list of nearby faults that have been reported to ensure that duplicate faults are not logged. If the fault appears to have already been logged and is in progress, the operator can inform the caller of the progress and even provide an expected date for resolution. If it appears that the fault has been resolved (closed on the system) then the operator can inform the caller accordingly. The system should display only nearby faults that were closed within the last month (or some other configurable time-period) and all open faults. The purpose is to enable the call-centre operator in establishing whether the fault has recurred or if a previously logged fault is being reported again. A fault identification number (ID) will be automatically generated for each new fault, and presented to the call-centre operator for conveying to the caller. This ID will be available to the public and to other agencies or utility companies. All subsequent transactions related to a particular fault must utilise the unique ID number.

Despite mechanisms to prevent duplicate faults being logged some may occur accidentally if the operator is unable to recognise that a duplicate is being reported or if the same fault is simultaneously logged by two different operators. Therefore in a future development phase it would be useful to have a consolidation method for identifying duplicate faults based on proximity and similarity in nature.

Once a new fault has been logged at the call centre it will need to be inspected in order to determine its validity, and the equipment and material required for its repair. The field worker tasked with the inspection will also be able to provide an accurate GPS location for the fault.

Should a caller phone in about an existing fault, it can be traced using the address (geocoded as explained above) or the fault ID. In both cases a reference number can be issued for the call which is tied to and based on the fault ID. This will enable reports to be compiled on the number of queries received against reported faults. This information could potentially be used to change priority levels but this will not be done for the first phase of the project. Only limited read-only information will be provided to operators on previously logged faults, such as the expected date of repair, and so on.

In the future, this system could also be extended to receive SMS and email fault logs and queries from the public. Faults may also be discovered and reported by field workers using their mobile devices. This is discussed in Section 3.1.

3 Fault Verification

Certain field workers, termed "fault investigators", are tasked with investigating and verifying the existence of faults. These field workers are issued with mobile device which will route them to the faults in their area of jurisdiction. Fault investigators should be routed to high priority faults before normal priority faults. Lastly, investigators should be routed to low priority faults. When in the vicinity of high priority faults investigators should be able to view faults of other priority levels which are nearby.

The routes are calculated by the device based on where the device is located at that point in time. Routes should take the form of destinations as well as actual directions. Investigators should be initially be presented with a list of all high priority faults and their respective distances so they are at liberty to decide which faults to address. A simple map should be displayed on the device in order to assist the investigator in reaching his/her destination.

When the investigator has visually identified the fault, he/she can then commence to file a fault report card. The elements of a report card are as follows:

Report card version
: This enables the system to keep of modifications to the report card questions over time. This need not be shown to the user.

Fault type
: Pothole, Drainage, Traffic Light, Road Marking, Accident, Signage, and so on.

Questions
: Each question will have a unique number, and question text.

Answer format
: The format of the answers to each of the question needs to be stored. Answers may take the form of a set of limited options, free-form text or numbers. Simple validation techniques should be applied where possible.

Photographs
: A limited number of photographs of the fault, which are obtained from the device's camera, can be included as part of the report.

GPS location

This is not directly supplied by the user. It is determined in the background while the report is being compiled.

The type of fault will have automatically been selected based on the information supplied when the fault is initially logged. However, the investigator can override this if necessary (eg. *drainage* instead of *pothole*). Once the fault type has been confirmed the report card questions are presented. Each fault type is associated with a specific set of questions. For example, in the case of a pothole, the report card questions would ask for diameter, depth, type of surface, extent of damage etc. Once the report card has been completed, and submitted (uploaded), the fault is seen as being formally verified.

It is important to note that the investigator may discover that the fault does not exist, or it needs to be dealt with by a different department, or it has already been resolved. These outcomes should be captured accordingly.

3.1 Fault Discovery and Verification in the Field

While an investigator is navigating to the location of a logged fault, he/she may notice another fault on route. The investigator should be able to file a report card and verify the fault. However, before the fault can be reported a check would need to be performed against existing faults in the system which occur in the vicinity of the discovered fault. These existing faults should be displayed to the investigator in order to enable him/her to make a judgement as to whether the fault is new, or has already been logged but not verified, or has been logged and verified. In the case of new faults, and logged but unverified faults, the investigator can submit an appropriate report card. If the fault has already been verified no further action need be taken.

4 Fault Repair

4.1 Work Orders

Once a fault has been verified by an investigator, steps need to be taken to repair it. The work that needs to be done in order to repair the fault is captured in a work order. A work order essentially consists of a number of tasks (activities) that need to be performed in order to repair the fault. These tasks may consist solely of a textual description or they may also include an annotated image to better illustrate the work to be done. A bill of materials (bitumen etc), and required equipment, is also associated with each work order.

Work order management is performed centrally at the transport department's offices. Work order creation must be restricted to certain staff members. Anyone who is tasked with creating work orders should be able to view all logged faults as a list or displayed on a map. The priority levels of the faults should be highlighted. The user should be able to:

- Drill down into the details of a particular fault by viewing the report card.
- Attach a work order to a fault that has been verified and does not have outstanding work orders. The user should be able to incorporate, and annotate, images from the original fault report card. Once the work order has been completed it will be issued, and await scheduling.

Users should not be able to modify faults (by attaching work orders etc) if they are currently being modified by another user.

A fault has only a single work order active at any one time. Once a work order has been verified (Section 5), a new work order can be attached. In future, there could be multiple concurrently active work orders which could be allocated to different teams. For example, a traffic light fault could involve pavement repair and pole installation being done by one team, and the electrical repairs being done by another team.

4.2 Work Order Scheduling

Work order scheduling is a separate process from work order creation. Separating the scheduling process enables one to optimally plan the deployment of repair teams.

The scheduling system picks up work orders that have been issued. A dispatcher will review the work orders and allocate them to repair teams based on priority, proximity, and team availability. It is generally expected that teams will be assigned a number of work orders which are geographically close to one another, have the same fault type, and require the same equipment.

The user should be able assign a specific repair team to a specific work order on a particular date. The system should enable the dispatcher to avoid scheduling conflicts. Suggestions for the manner in which work orders can be assigned are given below:

- As a first phase, and mostly manual, approach, the dispatcher could select a work order directly and simply choose the repair team, and the date and time for the work to be performed.
- This approach could be more automated by having the system allocate the date and time by scheduling the work order in the first available slot in the calendar. However, a high priority faults will preempt lower priority faults and when a work order is issued for a high priority fault the work order will be assigned to earliest possible time slot and displace lower priority work orders that were previously scheduled at that time.
- It would be advantageous to interact directly with the fault map when assigning work orders. A polygon could be drawn around a collection of faults with issued work orders which are displayed on the map. A repair team can then be selected and assigned to these work orders, or a filtered set (by fault type, priority, etc). The system would calculate the duration of each work order and insert the work orders into the calendar of the selected repair team. Once a day is full, the allocation will automatically proceed to the next day. The supervisor can review the proposed times in the calendar and make adjustments if necessary

For any option that is chosen it is important that:

- Work orders may be re-allocated to different team in order to balance workload.
- Work orders may be rescheduled if necessary. For a more automated approach, delays which are specified to the system will result in the automated rescheduling of all subsequent work orders.

4.3 Work Order Fulfillment

Repair team leaders will be issued with mobile devices. The work orders that have been scheduled for a given day will be downloaded wirelessly to the device when the repair team leader logs on. The repair team leader will be able to access the work order schedule and be directed to the work order locations.

When the repair team arrives at a fault, the leader will be able to view the tasks that need to be performed as per the work order. As each task is completed, it must be ticked off on the device either as completed or incomplete. If an incomplete response is selected then a reason must be specified. Images may need to be obtained during and after the completion of each task for quality assurance purposes. Upon completion, the work order report as well as any captured images will be uploaded, and the state of the fault will be updated to reflect that the work order has been completed. The repair team leader will then be able to navigate the team to the next fault on the schedule. The progress of the repair teams will be updated on the central scheduling system. In future, the performance data gathered will enable the dispatcher to plan and schedule more accurately.

5 Work Order Verification and Fault Resolution

The verification of work orders means reviewing the work done against the original fault that was logged. Work orders may be verified on the central system or in the field. After the verification process, a decision as to whether the fault has been resolved or requires further work has to be made. All of these aspects are discussed below.

5.1 At the Office

Supervisors, who more have elevated privileges over ordinary users, should have the ability to filter the logged faults on the office system so that only those which have completed work orders are displayed. Supervisors should then be able to view the work-order report which shows the actual work that was done on task-by-task basis. The supervisor can review the details as well as any supporting images that were submitted.

If the supervisor is satisfied with the work, he/she will be able to simply sign off the work order. This will update the status of the fault to closed (resolved) and work order will be marked as “satisfactory”. Closing faults is an important aspect to ensure that repair teams are not inadvertently dispatched to deal with the same fault. Closed faults never disappear from the system (for practical purposes an expiry period of ten years can be specified since the fault was last accessed).

Should the supervisor be unsatisfied with the work, he/she is required to create and attach a new work order which will address the tasks that were not completed to satisfaction. This new work order will be created with the status of issued and be queued for scheduling. The previous order will be marked as being unsatisfactory to indicate that there were unresolved issues. A reason needs to be supplied when marking a work order as unsatisfactory, and there are various possibilities which range from “poor workmanship” to “incomplete tasks”. There is strong likelihood that work orders may be incomplete or abandoned due to material shortages. It is essential that only one work order is active at any time on a given fault. New work orders can be attached after the active work order is completed irrespective of its outcome.

If the work done is questionable but is not possible to make a judgement from the work order report, then an in-the-field inspection of the work is necessary. The system needs to schedule this inspection and indicate that the work order is awaiting field verification.

5.2 In the Field

Inspectors (field-based staff) conduct inspections in order to verify completed work orders when it is not possible make a decision from the central office. Inspectors use mobile devices to receive scheduled inspections, to navigate to fault locations, and to perform the actual verification of work orders.

Whenever an inspector logs on to the system via his/her device, the device will download the ten work orders requiring inspection. If there are high priority faults, only these should be displayed at first. Lower priority faults will appear once the priority faults have been dealt with. Ideally, the faults should be sorted based on optimising the inspector's route so that the distance that needs to be travelled is minimised. As the inspector is able to view, at any a point in time, a number of faults that need to be inspected he/she may decide to override the optimal route that is being suggested. This decision could be made based on traffic information, unexpected road closures and so. Therefore the inspection list should be reordered to produce an optimal route based on wherever the inspector is currently located. The inspection list should be periodically updated in the background.

An inspector can view a particular fault requiring inspection by selecting it from the list. A map and turn-by-turn navigation directions will then be provided to direct the inspector to the fault. Once at the fault location, the inspector can review the quality of the work and verify the work order on the device, marking the fault as resolved or requesting additional work (as described in the previous section).

There are a numbers of inspectors working for the department and they should each be assigned a different set of work orders to inspect. Once a work order has been assigned for inspection it cannot be recalled and assigned to a different inspector. In a future iteration, it may be possible to implement load balancing. This would allow for the dynamic reallocation of inspection tasks based on the inspector's position and workload.

6 Unresolvable Faults

At any stage of the fault resolution process a fault could be closed as unresolvable by a manager, in which case, the state of the fault, and repair work done, is frozen. All further work on the fault is halted, and the attached work order is cancelled, that is, it must be removed from the calendar if already scheduled. This scenario might occur in situations where the scope of works is too large and may need to be issued as a tender.

7 Logging/Data Storage

Should anyone wish to investigate the series of events, a full audit trail will be available.

A comprehensive audit trail needs to be created for the system in order to resolve customer disputes and to facilitate the correction of errors. Logging or storage of the following data is required:

8 System Scope

The following aspects are beyond the scope of the system:

- The integration of this system with the department's stores management system which is responsible for the ordering, issuing and monitoring of the materials used in performing road maintenance.
- The integration of this system with the department's accounting system which is responsible for the costing of the work that is done.

- Security issues such as: the security of the information stored locally on the mobile devices and the security of the communication path from the mobile devices to the office system. Additionally, steps may be taken to aid the security of field workers such as allowing them to use the mobile device as a “panic button” if they feel threatened. This is also beyond the system scope.
- Lockdown of the mobile devices so that they can only be used for work purposes.
- Mobile device tracking and recovery in the case of theft.
- Allowing external repair contractors to integrate with the system.
- The handling of emergency complaints such as toxic chemical spills, road collapse, serious flooding, and the like. These events require an immediate response from a dedicated standby team while this system aims to address routine maintenance work.

9 Assessment

9.1 General

- The project brief is intentionally vague and possibly contradictory in some areas. You are required to make *reasonable* assumptions about various aspects of the system behaviour.
- The focus of this project is on the *domain layer* of the system. A large part of your analysis and design effort should concentrate on this layer. You need not cover the entire design space at a detailed level. Specifically, you should minimise the effort that you put into handling secondary concerns (from the point of view of this project) such as security, user interface design, and so on.
- You are required to apply the material that you are covering in this course to this project, including, use cases, problem frames, analysis and design patterns, domain-driven design and UML.
- You are required to create a prototype which demonstrates the key design decisions that you have made. This can be done in any mainstream object-oriented language. Remember, you are creating a proof-of-concept prototype to illustrate your particular design approach — not a full-fledged application. Each group member must be responsible for creating a *distinct part of the prototype* involving the *application’s domain layer*.

9.2 Assessment Form

This course project contributes 40% towards the overall course mark. The marking grid and assessment guide that accompanies this brief will be used to assess the project.

In order to map the assessed outcomes to an overall percentage, an algorithm is used. The weighting factors used in the algorithm are summarised in the tables below. Note that the specific outcomes within each component have equal weightings. There is one overriding rule: if any outcome category is rated as *Unacceptable*, then the mark for that component is capped at 40%; however, the mark can be lower than 40%.

9.3 Group Self-Assessment

Each group of n students is allocated $5n$ percent in terms of discretionary marks. For instance, a group of five is allocated 25 percent. It is up to the group to determine how

Project Component Weights	
Group Report	0.35
Individual Report	0.50
Presentation and Demo	0.15

Outcome Ratings	
Unacceptable	0.00
Poor	0.20
Acceptable	0.55
Good	0.70
Excellent	0.95

to divide this. The discretionary marks may be evenly split (5% each) if it is felt that all group members contributed equally to the project. If this is not the case, the group can acknowledge members who have contributed more than others by granting them a larger share of the marks. The maximum that any one group member may be awarded is 10%. The discretionary percentage for each group member is added to that member's overall percentage to determine the final mark for the project. An example of this, for a group of four, is shown in the following table.

Group Member	Overall %	Discretionary %	Final %
A	70	8	78
B	62	5	67
C	65	5	70
D	56	2	58

In order for the discretionary marks to be granted all group members have to agree on how the marks are apportioned and sign to this effect on a declaration form (refer to section 10). Note that this process is not intended to account for gross differences in effort. If you feel that a group member is not pulling their weight then try to resolve this internally. If this is not possible then discuss the issue with the lecturer.

If a student receives a rating of *Unacceptable* for any outcome then that student's discretionary marks are forfeited.

10 Deliverables

Group Report

Each group will be required to submit one concise project report (no longer than 15 typed pages) that includes at least:

- A discussion of the development methodology adopted by the group;
- A complete analysis of the problem domain and the requirements;
- A *high-level* or architectural view of the design and the areas of the design that were prototyped;
- The source code of the prototype on a CD.

Preparation of this report will be a group effort.

Individual Report

Each member of the group will also have to submit an individual report (no longer than 10 typed pages, excluding appendices) that focuses *in detail* on his/her unique contribution to the system design. This report must not simply repeat sections from the group report. It should minimally include:

- a brief but clear explanation of the role of the member in the group and the specific area of the project that they were responsible for;
- the analysis relevant to the part of the domain layer being modelled;
- the key design decisions in this regard;
- the implementation of the relevant parts of the prototype and the issues raised in prototyping;
- the modifiability and reusability of the modules designed;
- suggested refactorings to improve the current design and/or alternative designs and the tradeoffs involved.

Presentation
Each group will be required to present their project, and demo their prototype, to the class in no longer than 20 minutes. All group members are required to present. This will be followed by 5 minutes of questioning/critique.

Declaration
A page declaring the discretionary percentage split among the group members must be submitted and signed by all group members. *If the declaration is not submitted or not signed by every member then no discretionary marks will be awarded.*

The completed documentation and presentations must be concise and of a high standard, in accordance with accepted guidelines for report writing and presentation delivery that apply within the School of Electrical and Information Engineering.

10.1 Submission Deadline

Refer to the course homepage for the project deadline. Note that the presentations are due prior to the documentation.

10.2 Plagiarism

All instances of plagiarism will be severely dealt with. No two groups or group members may have identical or overly similar deliverables.