Chapter 4
A Smart Road Maintenance System for Cities – An Evolutionary Approach

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Abstract. One of the biggest challenges faced by cities today is maintaining their roads. Smart Road Maintenance can lead to more operational efficiency, timely response to citizens, and cost-effectiveness. Efficient and effective management and maintenance of a city's road infrastructure not only improves the quality of life for its citizens, but also makes the city more attractive for business investment. The IBM Kraków SWG Laboratory, in the cooperation with AGH University of Science & Technology, Kraków and the city of Kraków, created an innovative solution for road maintenance problems. In this paper we describe the challenges currently faced by many cities in road maintenance and how one could bring low-cost, ubiquitous technology to help cope with those challenges. This project also exemplifies the Smarter Planet/Smarter Cities initiatives being promoted by IBM worldwide.

4.1 Introduction

According to a World Bank report, for the first time in history, more than half of the world population is already living in cities [5]. By 2050, not only is the world population expected to grow from about 7 billion to over 9 billion, but also over two-thirds of that population is expected to live in cities [6]. While it is possible for brand new cities to be developed, most of the population growth and migration will happen in existing cities. This puts a considerable burden on many cities' already strained systems of transportation, roads, healthcare, utilities, etc. Thus the need for smarter management of city services is imperative. One such area that we focus on in this paper is the maintenance of road infrastructures.

Currently, many cities suffer from the problem of poorly maintained roads. There can be several reasons for that. For example, it could be insufficient maintenance budgets; or even if there are sufficient budgets, the reasons may be lack of timely identification, classification, and prioritization of maintenance problems.

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Sometimes it could also be the lack of proper information transfer and coordination among the various city departments and sub-contractors the city uses to repair the roads. In some cases, it could be just the poor quality of work performed by a sub-contractor and the lack of visibility to that at higher levels of city administration. Added to all these problems on the city's side is the citizens' perception that their municipalities don't do much for them. Often times when citizens complain about something, they have no idea if anyone is listening and acting on their complaints. Thus lack of responsiveness is also a major issue in many cities.

These problems have existed in many cities for decades. However with the advent of ubiquitous smart phones and integrated service management software, it should be possible now to address these problems much more effectively. There are already pilot projects in cities around the world exploiting smart phones to address such problems (e.g, CitySource [1], FixMyStreet [2]) . In a similar vein, our project proposes a Smart Road Maintenance System that allows smart phones (or even simple phones) to report road incidents and process them using a sophisticated service management software platform.

While what we describe in this paper falls into the general category of these referenced efforts [1, 2, 3], it differs in its breadth and focus. These referenced efforts focus on the front-end of problem reporting, while our project addresses the end-to-end solution, starting from the front-end incident reporting, through the back-end intelligent incident processing, it goes all the way to the problem resolution and other downstream activities. As our focus is more on the back-end, our work can be used to complement CitySource and FixMyStreet.

4.2 Solution Concept and System Structure

4.2.1 Concept

The concept behind our proposed solution is fairly simple. The city's road problems such as pot holes, broken water lines, fallen trees, etc can be easily reported by a citizen passing by. For example, when a citizen notices a pot hole in the road he can take a picture of the pot hole and email it to a well-known address published by the city Government. Many phones are equipped to capture GPS coordinates of the location where the picture is taken. This can be transmitted as metadata along with the picture to the city's published email address. The city receives the incident, locates it on the map and then appropriately processes the incident. This concept is illustrated in Figure 4.1.

There are a number of advantages in a system that is so simple and yet so effective:

- Due to the ubiquitous nature of cell phones today, any citizen can notice road problems and report them.

Fig. 4.1 Concept Illustration

- If someone has a cell phone with a camera, then they can take the picture and send it in as described above, but even if someone doesn't have a camera, they can call a published number and leave a recorded message describing the issue. (As we will describe later, these recordings can be processed using a speech-to-text translation software and then using text recognition to create incidents out of them).
- If someone has a smart phone, the input can be made even more structured by a dedicated mobile application downloaded by the citizen to his/her cell phone (By the way, this is the approach taken by CitySource, and others [1, 2]).
- One of the attractive aspects of this email based reporting is that the sender can be acknowledged by the city and even notified when the city acts on the reported incident.
- This ability to talk back to the reporting citizen is helpful in other ways also. For example, to send him back a reference number that he can use to track the progress of his incident. Or maybe even claim some rewards from the city, if such incentives are offered by the city.

A question that naturally arises is why do we choose citizens to report problems rather than using some technology like smart cameras that can scan roads and identify problems? In our experience, involving the citizens is cheaper and politically a more appealing solution than a fully automated one for many cities. Also, this way the costs are low and the citizens feel included.

4.2.2 System Structure

The picture below illustrates the system structure and its logical components (see Figure 4.2).

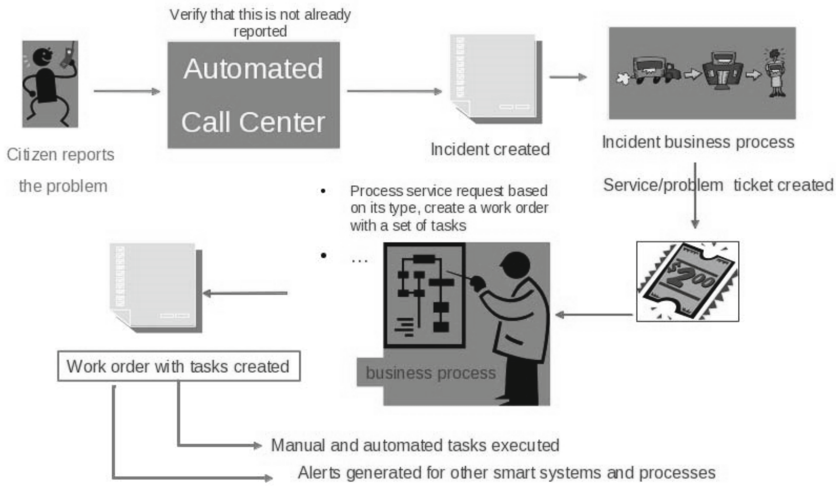

Fig. 4.2 System Structure of the Solution

The structure of our proposed solution is depicted in Figure 4.2. As can be seen, it is fairly straightforward. The citizens report problems with the roads, and the problems go through an automated call center for appropriate de-duplication (i.e., eliminate or at least reduce duplicates). An incident record is created then from the problem report. The incident is then subjected to an incident business process, where appropriate classification and prioritization is done. When it is determined that the incident requires some action, a service request is created. The service request goes through its own business process, where a determination is made on whether some work needs to be performed, and if so a work order or a set of work orders is created. These components of the solution structure and their variations are described below.

4.2.3 Component Descriptions

4.2.3.1 Input

There are multiple ways in which incidents can be reported. The simplest being someone taking a picture of a pothole (or for that matter any road problem) and sending it to the published city email address (e.g., e-mail: `road-problems@yourCity.com`). There are a number of other ways:

- Simple phone call to a published city phone number and leaving a voice message
- Web interface, where a form can be filled out from a personal computer, for example.
- Web interface, accessed via smart phone
- A dedicated mobile application on a smart phone (e.g, iPhone, Android or Blackberry)
- An SMS message, etc.

4.2.3.2 Automated Call Center

All calls, whether delivered through phone messages or emails, or web-based forms, need to be processed by a call center. While this in theory can be a manual call center, in practice it needs a fair amount automation, to cope with the volume of incidents generated as more and more citizens report problems eagerly. One of the main functions of such a call center is validation and removal of duplicates.

4.2.3.3 Incidents and Incident Business Process

Once a reported incident is validated (i.e., not a duplicate), it must be registered and subjected to a process of classification and prioritization. Some city administrations may want certain class of events to be physically verified by one of their city personnel. For example, some city Governments may choose not to trust any incident unless it is verified by a designated department staff. This becomes part of the business process. Some incidents may be classified as dangerous (e.g., a puddle of water covering a big pot hole) and some urgent attention is needed even before someone repairs it. These actions are also triggered based on the classification. Sometimes incidents may be combined into a larger one.

4.2.3.4 Service Request (Ticket) Creation and Process

Once an incident is verified, classified and prioritized, someone needs to act on it. This action is requested via a service request (also called service ticket). A given incident may result in one or more service requests. Service requests are processed using their own business process and fulfillment of service requests results in work orders being created.

4.2.3.5 Work Orders and Events

A work order is another business object, much like incidents and service requests. It is subjected to its own business process or workflow logic. Work orders in general contain tasks that need to be performed. As a side effect of work order execution, events (or alerts) can be generated to communicate with other systems (e.g., repairing a pot hole may require co-ordination with the water department to turn off/on water lines). Some work orders may have child work orders that are delegated to city's sub-contractors. The work order management system ensures that all work, whether performed by the city or sub-contractors is properly tracked and coordinated. Keeping a history of work orders is also helpful in making warranty claims on sub-contractors (and in the long run developing a vendor rating system.)

4.3 Making Things Smart

The process of reporting and handling road incidents or service requests may look fairly straightforward and routine. However, the use of appropriate technology makes the process more efficient, scalable and affordable. This is what makes it smart, compared to the current way most cities approach road maintenance today. In general, making any city solution smarter involves leverage of technology to reduce cost, increase speed, and providing better services.

In what follows we describe some example 'smarts' that can be put into a road maintenance solution. Some of these have already been implemented in our pilot project and some others are future directions. (The current status is summarized in the Results section.)

4.3.1 Faster and Mostly Automated Problem Reporting

Smart phone technology can be leveraged to quickly and automatically report problems. For example, with a dedicated smart phone application, one can take a picture, create an incident attaching the picture and its location meta-data, and send it to the city; all in a matter of a few clicks.

4.3.2 Automated Localization and De-duplication

The location information, for example the GPS co-ordinates of where the picture was taken, are sent as meta-data and using the APIs of a mapping service the incident is located on a map (see Figure 4.3).

We can also eliminate duplicates by comparing the incident meta-data (for example, by seeing whether two incidents have very close GPS coordinates).

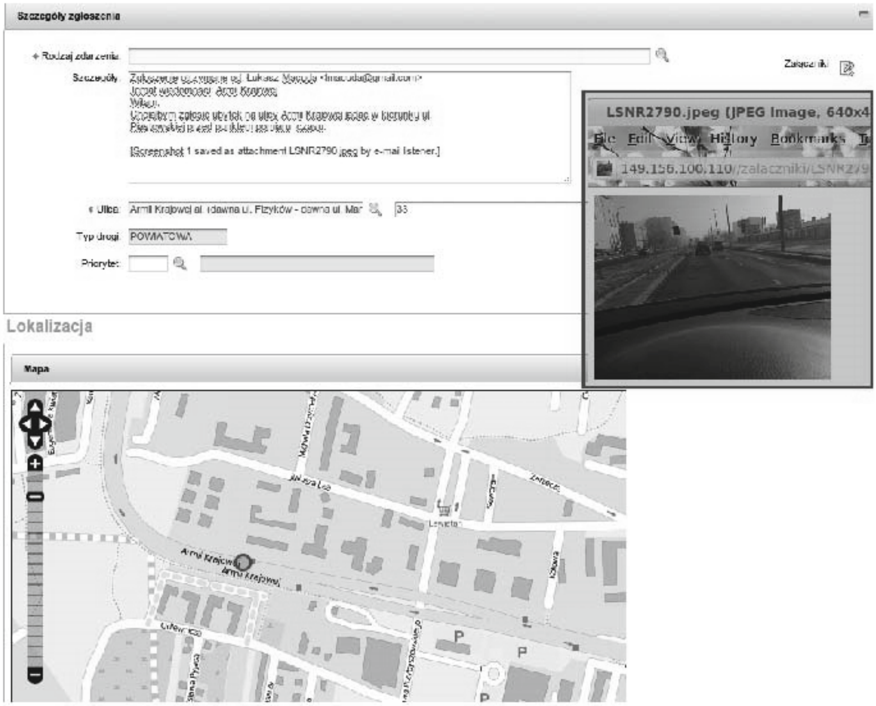

Fig. 4.3 Locating the incident on the map using GPS coordinates in the metadata

4.3.3 Automated Processing, Classification, and Prioritization

The incident records created as above contain structured data and hence can be processed by software very well. For example, based on the location of the incident and the citizens marking of severity level, it can be classified and prioritized automatically.

4.3.4 Rule-Based Processing of Incidents, Service Requests and Work Orders

In general, depending on the service management software used, it might be possible to process all objects (i.e, problems, incidents, service requests, and work orders) based on business rules. [Figure 4.4 depicts the workflows we implemented in our City of Kraków pilot project. The tool used was IBMs Tivoli Service Request Manager. The thunderbolt icons on arrows indicate actions (snippets of Java code) that get called when those state transitions occur.]

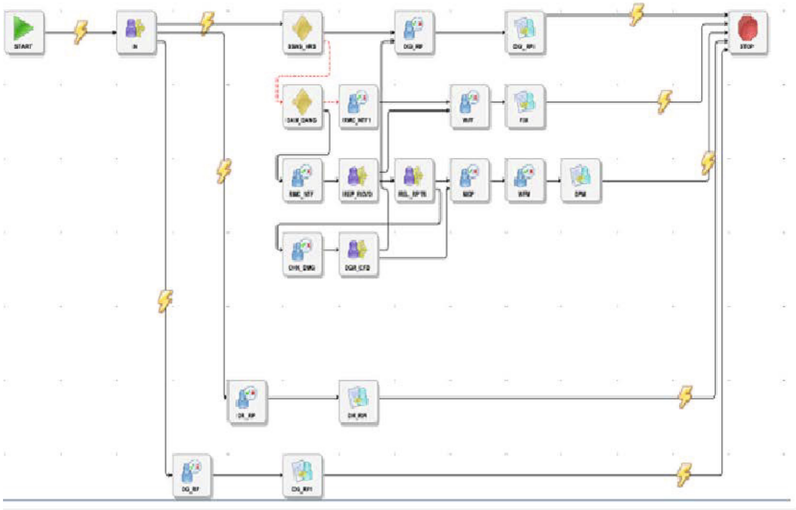

Fig. 4.4 Incident handling Workflows can incorporate business rules

4.3.5 Analytics

Since all data is gathered automatically, it is easier to analyze and gain insights. In general making any city solution smarter involves leveraging technology to reduce cost, increase speed, and providing better services.

4.4 Results and Project Status

4.4.1 Results

Most of the design has been implemented in a pilot project done for the City of Kraków (Poland). Here are some details of the pilot implementation:

- Three input methods of creating road incidents were implemented: photos from phones, regular email, and website-based form.
- IBM Tivoli Service Request Manager (TSRM) product was used to implement the service desk (call center). Using its email-listener interface, incident records were automatically created from received emails. Both smart-phone based picture emails and regular emails came in this way. The web application was fairly straightforward to build as a servlet that talked to TSRM to create an incident.
- The image meta-data was used in conjunction with Google^{TM} maps (as the map provider) to locate the incidents on the city map. (In a later implementation we have supported OpenStreet Maps as yet another map provider. The architecture is flexible enough to work with different map providers.)

- The incident data was also exploited to automatically identify the resource the incident applies to (e.g., streets were treated as the resources/assets to which incidents apply). In the pilot implementation, we have input all city streets (street segments) as assets into IBM Tivoli Service Request Manager. Based on the GPS coordinates of the incident, we were able to automatically identify the road segment that the incident was on. This also helps to automatically assign the incident to the City employee (like a dispatcher or supervisor) responsible for that road segment.
- De-duplication, classification, prioritization, etc. were done manually by the dispatcher (a human role) assigned to the incident. (in a later implementation, we have done some automated de-duplication by exploiting the proximity of GPS locations. I.e., they don't have to be identical but if they are close enough, then they are treated as duplicates.)
- Analytics: In the pilot implementation we only produced some simple analytic reports that calculated the average duration of problem resolution. However, there is a lot more potential here. As one can observe, the system accumulates a wealth of information with timestamps as the problems are reported, incidents tickets created, service requests created, work orders generated, passed on to subcontractors, and tracked. Overtime this can be exploited to identify bottlenecks in the system and reduce the overall cycle time. This leads to better citizen satisfaction besides optimizing the use of limited city resources.

The resulting pilot system was deployed for use by the city construction company (ZIKIT A City of Kraków Company responsible for Road Maintenance) and was successfully used for a pilot period of about two months. Initially, the users were restricted to be ZIKIT personnel only, but once it was extended to ordinary citizens via publicity on ZIKIT's website, several citizens participated and the number of incidents went up significantly.

In the pilot project the final part of generating work orders and tracking their progress with the repair companies was not implemented. (This is currently done by ZIKIT using their internal work management system. Changing that was beyond the scope of pilot). As a result there are no measurements on the change in citizens' satisfaction due to the pilot. We did however receive several favorable comments that the citizens and the press liked the pilot system.

(As a follow on to this project, we are pursuing an extended pilot in 2013 that is implementing the sub-contractor functionality as well.)

4.4.2 Status

At the time of the original writing (mid 2012), we started moving past the pilot in two parallel directions. One is to implement an extended pilot for the city of Kraków with more functionality and scope of citizen coverage. The other, working jointly with AGH University, is to push the Research and Development direction to experiment with more 'smarts' in de-duplication,

4.5 Comparison to Related Work

4.5.1 Similar Systems

There have seen several efforts similar to ours. For example, CitySourced, a California-based company, offers a smart phone application that can be downloaded by citizens from their website and used to report civic issues to their city Governments. All the reported events accumulate at CitySourced server. City Governments can set up a business arrangement with CitySourced to get incidents relevant to their city and then act upon them. The interface for citizens is fairly simple to report civic incidents like pot holes, broken water mains, graffiti, street fights, illegal dumping, etc. All these incidents are also shown on a regional map on CitySourced's web site.

A nice feature of CitySourced is easy reporting and intuitive depiction of incidents on a regional map so citizens know where all the reported issues are. Like our pilot system, CitySourced smart phone application can also take a picture of the incident and report it to the CitySourced.com website with the picture and some additional information. Further the reported incidents follow an industry standard (Open311 [7] events), making it easy for other systems to consume them. The citizen can also look up the status of any incident (regardless of who reported).

Another very appealing feature of CitySourced is that it is a SAAS (software as a service) model where a city Government doesn't have to buy or implement any software. It simply subscribes to civic events from the service and receives them in Open311 format.

In comparison, our solution also has the simplicity of reporting city problems using a cell phone, and we make it even simpler than them. For example, we don't require a smart phone application, though we could use it, if one exists. We can let even ordinary cell phones (i.e., not so smart) take pictures and report problems. Our goal was to minimize the barriers to adoption. If people don't need any special software then the solution is easier to adopt.

Another system similar to CitySourced is FixMyStreet which seems to be widely used in the UK. This system primarily uses the web interface for citizens to report problems. The web interface is easy to use and it presents a map for citizens to locate their problem on the map. It also shows already-reported problems in the vicinity of the problem one is about to report. This allows for some de-deplication and location work to be avoided as the citizen entering the report will avoid reporting duplicate incidents.

FixMyStreet also has reports by area (city) where they can show a summary of total problems reported, newly reported, old and fixed, and not fixed, etc. This gives a good view to citizens how effectively their municipalities are dealing with their reported problems.

There are other systems similar to the above two. For example Naprawmy [3] in Poland is a community project that is being offered on a voluntary basis to cities.

All of the above solutions focus on the input subsystem of an overall city infrastructure maintenance system. Also these systems are not limited to road problems, but allow any kind of city problems to be reported. In contrast, our approach addresses the end-to-end solution, with more focus on the back-end processing of reported problems. All the other compared systems don't do much backend work.

End-to-end solution: It is probably useful here to distinguish an end-to-end solution for road maintenance from other solutions that only address a subset of aspects. At one end of the solution is the citizen that notices a problem, reports it and expects a response/resolution within a reasonable amount of time. As his/her problem enters the system and as it gets transformed into an incident, then as a service request, then as a work order and then as a project (or a set of tasks), we need to have appropriate management systems (e.g., including classification, prioritization, deduplication, etc.) for each of these transactions. Further, for continuous improvement these systems also need to generate measurements and allow for tuning. At the far end of the solution, after the problem is resolved, the originator needs to be informed and a set of metrics need to be collected for evaluating the efficacy of personnel/contractors doing the work. Now, an end-to-end solution needs to focus on all stages, not merely reporting the problem via a cell phone or merely generating metrics on how long the resolution took. While the end-to-end solution must address all stages, it is not necessary for a single product to address them all. The solution can be composed of multiple products focusing on different aspects/stages.

Besides being an end-to-end solution, ours also focuses on flexibility and pluggability. Thus it is possible for our solution components to be replaced by other products that fulfill specific functions. For example, we could replace or augment our solution with someone else's mobile application that produces Open 311 events to report problems.

All the above compared systems can be complementary to our solution. While all of them can use some analytics based on incident data, we have the ability to gather more data and apply more analytics on the backend, because of our focus on backend processing.

To summarize, our system has the following differences:

- We chose a low barrier for adoption by citizens by providing multiple and simpler ways of reporting
- We provide an end-to-end solution, going all the way from reporting problems to analyzing them to classifying/prioritizing them, to finally turning them into work orders and tracking them.
- Due to the end-to-end focus, we have more ability to automatically gather data and leverage data analytics for better insights and more automated means of coping with scale.
- Architecturally, we have pluggability to replace components with best of breed implementations.

4.5.2 Related Work

The work we have undertaken at IBM is one of several projects within IBM under the umbrella of Smarter Planet/Smarter Cities solutions. IBM has proposed a strategic architecture and delivered a platform upon which Smarter City Solutions can be built. This is called Integrated Operations Center (IOC for short). It is an integrated offering of several IBM software group products that provides the following capabilities:

- Provides a unified view across all city agencies
- Allows supervisors to monitor and manage a range of services
- Enables agencies to respond rapidly to critical events
- Delivers situation awareness and reporting
- Streamlines management of resources and critical events
- Integrates with open-standards connection points to existing and future systems

IOC quickly allows the user to get an understanding of what, who, why and where attributes of an issue or potential issue.

The following graphic expresses the Smarter Cities Operations vision of IOC (see Figure 4.5).

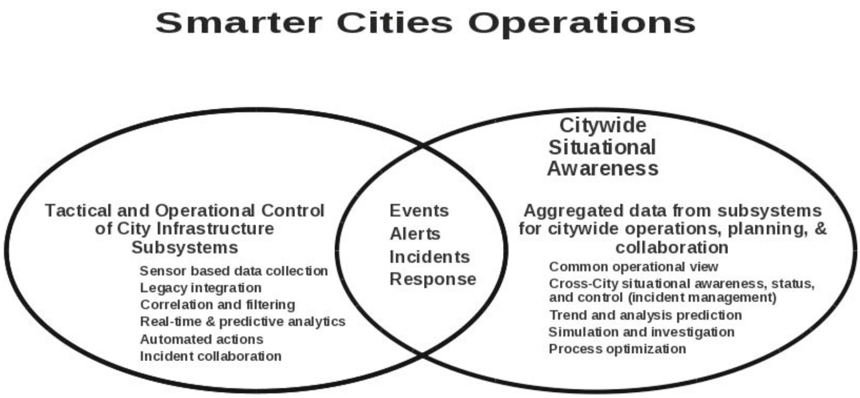

Fig. 4.5 IOC's vision to optimize city-wide operational systems

The smart city solution presented in this paper becomes a particular subsystem (city's road infrastructure) solution within the larger framework of IOC-based smart city system. There can be several such subsystems, and IOC facilitates integration and communication among them. In particular, appropriate events from one system to another are communicated via events built using an open protocol (Common Alert Protocol or CAP events). At a higher level IOC facilitates filtering, aggregation and analysis of data to enable city-wide visibility and optimization across city's subsystems.

4.6 Conclusion and Future Work

In this short paper, we have described a very simple and yet pragmatic approach to report and resolve cities' road problems. It relies on using ubiquitous technology and involving citizens to report problems. It leverages powerful service management software that has hitherto been applied in other industries (e.g., IT, manufacturing, and other heavy industries) for public service. Many of the solution ideas expressed here have been successfully implemented in a pilot project for the City of Kraków.

We have taken an evolutionary approach to the problem in the sense of introducing changes gradually and realizing commensurate benefits along the way. For example, we didn't require the phones to be smart phones and run our special software, we didn't require a city change its business process completely, or change the way it interacts with its subcontractors and so on. This gradual change is very important for cities to change their culture and embrace a new technology.

There are many directions for future work in this area:

One is certainly making the solution operational to full cities rather than pilot areas. This is the usual process of hardening the software and the business processes to be robust enough to meet the scale challenges.

A second direction is to put more 'smarts' into the solution components. In particular, de-duplication of incidents by exploiting image recognition and text recognition.

A third direction is to integrate the solution into a broader industry framework like IBM IOC, so that the solution can emit/consume alerts/events to & from other subsystems. This allows the road maintenance system to contribute to overall optimization of city operations.

A fourth direction is to exploit data analytics to make the solution components like Automated Call Center, Incident/Service request/Work order business processes to be more adaptive. This provides the obvious benefit of continuous improvement to the solution described in this paper.

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