A Mutilple-Level Assessment System for Smart City Street Cleanliness

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***Abstract*—Advancement in mobile, cloud technologies and IoT has made the world even smaller and connected like never before. It has become a challenge and an opportunity for cities to leverage these growing technologies to solve real city administration problems. Cities are in the transformation state to become state of the art smart-city using these technologies. This paper is about the automation of street cleanliness assessment in near real-time. It answers the question of how can we assess the status of streets more efficiently and effectively. In order to address the problem, this paper proposes a multiple-level assessment service system on how the cleanliness status of streets is collected using mobile stations, connected via city network, analyzed in the cloud and presented to city administrators online or on mobile. The real applications show the usability and feasibility of our system. This also gives opportunities to city residents to participate and contribute towards making the city a better place.**

Keywords- Smart City, Street Cleaning, Litter Detection, Machine Learning, Cloud Computing, Dashboards

I INTRODUCTION

Street cleaning is an important city service, which involves a set of activities concerning the cleanliness of the street (usually defined as pavements and adjoining edges of roads and grassed and planted areas) [1]. Therefore, it involves street-sweeping (whether manual or machine), litter-picking, the uplift of fly-tipped refuse and the removal of graffiti and flyposting. When the street cleaning service is ineffective, the evidence is visible. And it could cause a significant impact on the quality of life and the attractiveness of its neighborhoods, towns and cities [2][3]. Moreover, people believe that there are the links between environmental problems and other forms of disorder and crime in cities [4]. On the other hand, good quality street cleaning service in a city provides and contributes the good environmental quality in its communities and neighborhoods, which can help urban development, make places attractive to tourists, investors and mobile workers [5]. Moreover, the effective street cleanliness could reduce the costs in cleaning underground water systems for cities.

In 2016, the city of *San Jose* has set up its goal for 2020 to provide a real-time city dashboard based on its city map to present the city street cleanliness to the public. The major objective is to provide more cost-effective and efficient street clean services and improve the quality of life for its neighborhoods by providing a more attractive clean environment. Since 2017, the research center of Smart Technology, Computing, and Complex System in *San Jose* State University has been teamed up with the Environment Service Department (EDS) in the City of *San Jose* to develop an innovative smart digital street cleanliness assessment service system, known as *SmartClean*, based collected camera-based images using a cruise car on city streets. *SmartClean* is developed based on a well-defined street cleanliness assessment model with digital standards using machine learning technologies. In summary, the major contributions and distinct features of *SmartClean* service system for the city of *San Jose* are highlighted below..

- The system implemented the first and innovative hierarchical grid-based city street cleanliness assessment model [14] for digital processing, map-based regional analysis, street cleanliness pattern analysis and prediction.
- The system is the first one supporting automatic detection of diverse city street litter objects using machine learning techniques [13] based on collected camera images from the mobile stations as well as users' images. Different neural network models are used here. Based on our recent case studies in 2017, different types of litter object detection could achieve over 70% to 95% accuracy for major classes [13].
- After the system deployment, the system will be the first cloud-based comprehensive mobile enabled service system for city street cleanliness assessment and diverse services.

The rest of the paper is organized as follows. Existing work about smart city cleanliness is surveyed in Section II. Section III gives an overview and detail of our assessment model used in the paper. Section IV shows the architecture of our model. The implementation and case study are provided in Section V. Finally, Section VI concludes the paper.

II RELATED WORK

Based on our recent online search and literature survey about the city street cleanness, we found that many cities, industries, and IoT evangelists are still talking and looking for innovation solutions to address this challenge and need, even though there are some publications discussing the related issues and solutions. In addition to some case study reports [1][6][7], the closely related initiatives and solutions are summarized below.

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Clean Street LA [8] is an initiative challenge launched by the Landon City Mayor, and its objective is to use the ESRI GIS tool to map and plot the street cleanliness status block by block. Multiple layers and grids are created to reflect different parts of the city. Cleanliness information on the streets with a cleanliness score is visualized on a map. This information is used to decide the area that requires attention and cleaning services. However, the limitation of the system is that the monitoring is limited to Garbage bins and cannot be extended to monitor city streets.

LondonCleanStreets (UK) [9] is a crowdsourcing-based system which can keep the streets of London clean with cloud computing. Also, LoveCleanStreets is a crowdsourcing based online portal, which has a mobile app for the public to snap pictures and submit to local councils. This is widespread in UK and surrounding countries. It has an interactive map using Microsoft silver-light technology. Reports illegal dumping, potholes, and graffiti complain and shows clean-up time has improved by 87%.

SmartBin [10] is an intelligent monitoring solution which can enable waste management and recycling companies to optimize their collection operations and maximize the use of valuable resources. They do this by deploying SmartBin wireless ultrasonic sensors to a wide range of containers and using the data intelligence to drive operational efficiencies including optimized routes, asset tracking, and cost analysis. SmartBin sensors leverage the latest in IoT and cellular network technologies. However, the limitation is that the information is fed manually into the system. Also, the system is not real time and requires human intervention to update the status.

Spot Garbage [11] is a crowdsourcing approach based on the public inputs about the street clean status, where a crowdsourced platform is developed to use the pictures contributed by the public. The process of trash detection is automated. The limitation is that the litter in the images is not classified into object classes.

In [12], a mobile app is developed to evaluate the Street Cleanliness and Waste Collection Service. This app is based on a Plan of Indicators that can be used to evaluate the Street Cleanliness and Waste Collection Service of Santander municipality. Specific methodologies for calculating and evaluating 59 indicators have been developed to obtain information regarding the status of the different elements of the service. Pearson correlation coefficient results suggest that an inverse relationship between the Street Cleanliness Index values and the Frequency Street Cleanliness Services/population density ratio exists.

III ASSESSMENT MODEL - LDAS

A. Overview

Fig.1 shows the various modules and the interconnection between them. The proposed system has three layers.

- **Edge:** This layer is the layer where the data collection takes place in the form of images from streets. This data along with location coordinate is sent to cloud for processing.
- **Cloud:** This is the layer where the images are processed using analytical tools, created or fed the training model. Results from this layer fed to the end user database for visualization and reporting.
- **User:** This is the layer where reports are generated based on the Cloud processing. These results are visualized for city and community.

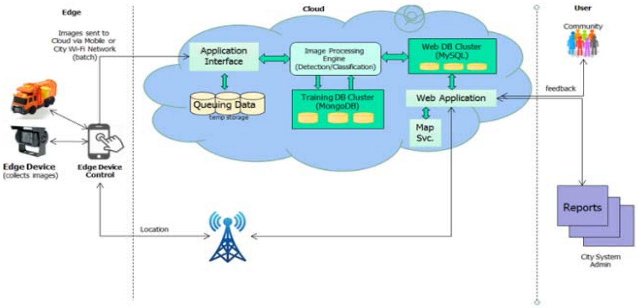

Fig. 1 the Assessment System Overview

The proposed model depends on various attributes which need to have well defined before and are assumed. Assumptions are made in the following:

- Fixed image resolution and camera angle.
- Vehicle speed is approx.15 – 25 mph.
- Picture covers 150ft. of distance.
  - Pictures are collected every ~3 sec.
  - Set of four pictures are collected every spot in each direction.
  - Multiple pictures collected to increase the confidence level of the machine learning system.
- Start and End Locations are predefined.
- Stable Cloud connectivity requires continuous stable connection in order to achieve online image transmission or offline image transmission
- Data is unique and is collected on a weekly basis for the entire city. This can be customized.

B. Multi-level Assessment Model

Litter Detection Assessment System (LDAS) providing the cleanliness assessment is done in layers. Lower layers contribute to layers above. Top layer generalizes the results of layers below. On a high level this model is divided into four layers.

Layer 1 is the first layer which defines the city area overall and sets the scope of assessment. This covers all streets in the city and is the base layer. **Layer 2** is the second layer where a city is divided into areas from Layer1 based on the city plan. Each area has a code. It may not be same as zip code but would be a group of GPS locations and distance.

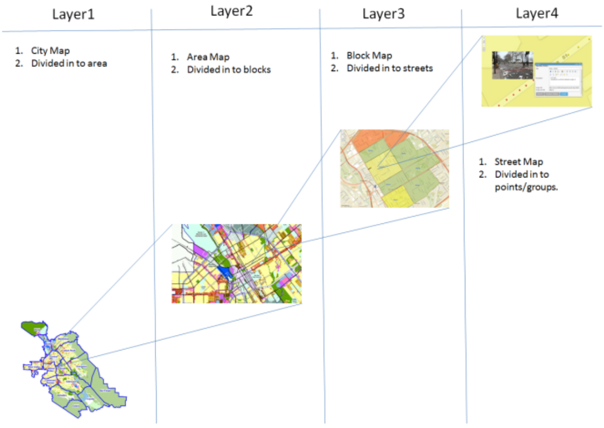

Fig. 2 Assessment Layers for San Jose.

Layer3 is the third layer where each area is divided into blocks. Each block is uniquely identified by a combination of area and block name. **Layer4** is the top Layer which represents individual streets in the block with individual data collection points called grid points.

Fig.3 shows the hierarchical view of *San Jose* City. From the figure, we can see that city represents entire city divided into different areas. It is divided into no. of Areas (represented by a circle) E.g. Central *San Jose* or Alum Rock. Each Area has a number of blocks e.g. 20 in Central and 16 in Alum Rock. Color represents the cleanliness level of area overall. Area Value (AV) is indicated with an average of results from each block within the area.

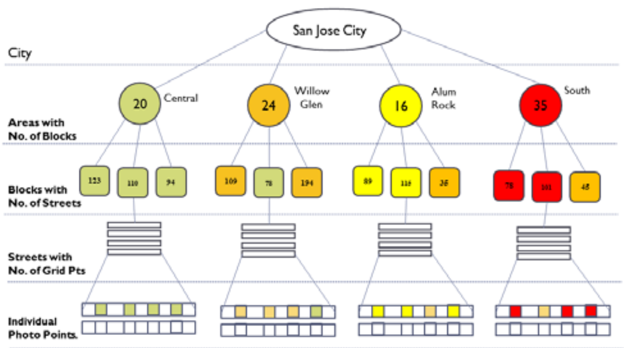

Figure 3: Multi-level Assessment Model

A grid is used to describe detail pictures of each point. The formal definition of a grid is described in the following:

Fig. 4 shows an example of the grid architecture. In the figure, all blocks are divided into several *Grid Point* and *INodes*. Then *INodes* are also divided into subsections with *SNodes*. Each *grid point* has at most four picture points.

All blocks collectively represent an area. The different color-coding scheme is used to represent cleanliness level for each area. Table 1 describes the different street assessment levels. Grid Point is composed of all the picture points in 150ft Radius. All pictures within this range generate the collective value which indicates the cleanliness level of the point. Collection of grid points represents the Block. This includes the streets within the block based on the latitude (lat.) and longitude (long.) and distance in miles but can be customized. It is assumed that the distance between two grid points is 150 feet.

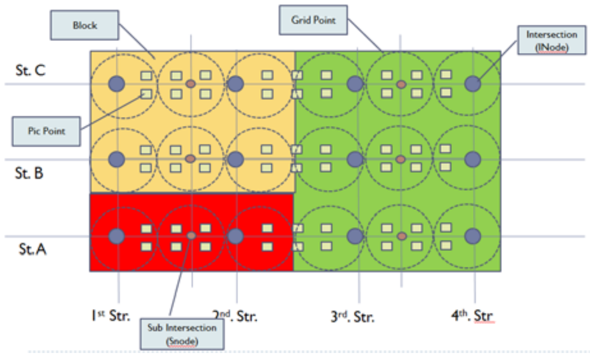

Fig. 4 Layer Point Plot.

Tabel 1. litter levels along with color code

Color	**Level**	**Desc.**
Green	A or 1	Not Littered
Yellow	B or 2	Slightly Littered
Orange	C or 3	Littered
Red	D or 4	Very Littered

Group Point is composed of all the picture points in 150ft Radius. All pictures within this range generate the collective value which indicates the cleanliness level of the point. Collection of grid points represents the Block. This includes the streets within the block based on the latitude (lat.) and longitude (long.) and distance in miles but can be customized. It is assumed that the distance between two grid points is 150 feet.

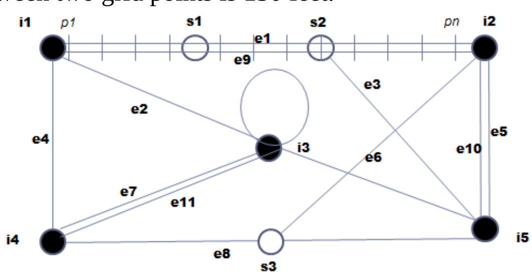

Fig. 5 Block Nodes and Edges.

Fig. 5 shows a block with intersections represented in solid dark circles as Nodes i_1, i_2, i_3 … i_N, white circles represent the intermediary road joins. Joining two nodes are Edges represented by e_1, e_2, e_3… e_N. Each Edge represents one-way traffic. Points, where pictures are taken, are represented as $p_1, p_2, \ldots, p_N$. Directed Graph (G) is used to represent entire city as one big graph as each road has a direction.

A graph is defined as $G= (N, E)$ where N is the set of nodes and E is the set of edges. Each edge $e \in E$ would have a starting node and ending node represented as $e = (i, e)$ where i is nodes and e is edges.

$$e= (i\ (source), I\ (term)) \quad (1)$$

Each photo point (shown as Pic Point in Fig. 4) has a value from the ML system represented by pV (point value) between i_1 and i_2. All values for each point are added and the average is generated for each photo point pV using:

$$pV_{(i1-in)} = \sum_{p=1}^{n} pi / n \quad (2)$$

Once pV is calculated, the sum of n pV in a range from both directions are averaged to generate the average value of grid point (shown as a circle in Fig. 4) gV (grid Value) using:

$$gV = \sum_{g=1}^{n} gi / n \quad (3)$$

Block constitutes all gV in a distance x which is a custom value and is a collection of all the pic point and respective grid points as you can see in red, yellow and green. Each color represents block average (*bV*) representing the cleanliness level. This is calculated by the average value of all the grid points in a block using:

$$bV = \sum_{b=1}^{n} bi / n \quad (4)$$

Fig.4 is also an example of the visualization of representing the calculations above. Validation at each photo point:

1. Four pictures from each camera are clicked in quick succession.
2. All pictures are associated with the date and time and also with the geo location in the as latitude and longitude.
3. Each camera has a predefined angle and resolution which can be customized and covers defined range 20ft.
4. All pictures are sent to cloud for analysis and assessment value is returned.

From Fig. 5 *i1* and *i2* are connected with two edges and similarly *e5* and *e10* are. These two edges represent two lanes of the same road. Every picture point on either side of the road would be part of same grind point and will be validating each other to confirm the cleanliness of the same point. This would base on the GPS coordinate of each photo point.

All blocks collectively represent the area. The different color coding scheme is used to represent the cleanliness level. Tab. 1 describes the litter levels along with the color code.

IV ARCHITECTURE

Smart City Infrastructure has various components. Below shows the components required for the cleaning infrastructure. We are going to explore the use and application of machine learning, mobile, and cloud computing, Big-data, Databases, Web and UI technologies and solutions to address the city cleaning issues. Big data analytics implementation along with machine learning would create an autonomous system, which shall serve as a self-detection engine to analyze the data on the fly. Mobile system using the latest available wireless and *Wifi* networks would establish the secure network connectivity between the edge device, cloud, and the city infrastructure.

The system is divided into three major segments, which is shown in Fig.2. Below is the high-level view of each segment.

Edge: This is the edge layer where data collection takes place in the form of pictures and location coordinates from streets using a smart vehicle with a camera called Mobile Station. This data along with time stamps are sent to cloud for processing over wireless or *Wifi* networks. At this layer, mobile station controller and mobile apps are the interfaces to the users. A mobile app is created to simulate this layer.

Cloud/Server: This is the layer where the images are processed using analytical tools, created or feed to the training model. Results from this layer fed to the end user database for visualization and reporting. This layer runs various services like web application servicer to connect to multiple mobile stations and receive data, database services, and Web server services. In our practical system, Amazon Web Service (AWS) is used to simulate the cloud enabling the connectivity between the mobile stations and cloud services for city administrators.

User: This is the layer where users, city administrators and residents can interact with the system. A dashboard created for city admin to monitor and control the system as a single pane of glass. A map view can see the street cleanliness level. Analytics shows various statistics on different sections of the city, management, and feedback of the system. Various reports can be generated based on the user requests. These results are then visualized for city and community.

A. High-Level System Layers.

The approach is composed of different layers in order to have more flexibility and scalability. Each layer has a different component and functions; which are maintained independently to minimize the impact on the entire system. Lower layer contributes to the layer above. Upper layers depend on lower layers. High availability is set to be achieved by using a clustered approach in the cloud. At a high level, there are two partitions of the system as shown in Fig. 7.

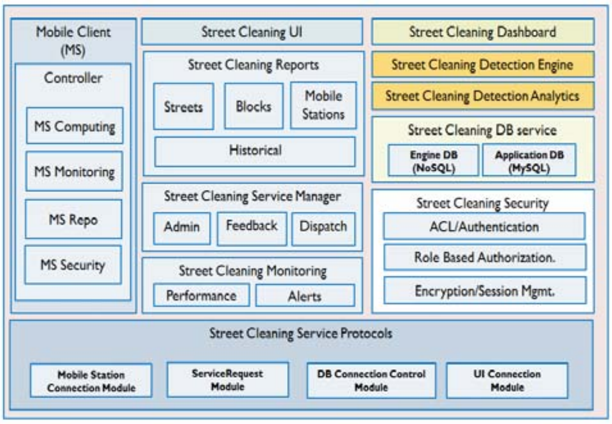

Fig.7 High-level Architecture

Edge Service or Mobile Station – This is the set of services run and managed on Mobile stations, which also serves as the client to cloud system. These are trucks or special vehicles, which connect to cloud service and updates continuously with latest updates. They have a local controller to manage edge service and have their own computer, repository, security and communication protocols for cloud connection. There is also a mobile app where the users can communicate with the cloud. This layer is heavily dependent on the network and needs to maintain a persistent connection with the cloud in order to have a real or near real-time communication.

Cloud Service or Server Side – This service includes various sub service and is composed of many modules or layers, which interact with clients and with each other and are running continuously. UI and Dashboards are setups for city administrators and other city officials. Part of it would be visible to public. Reporting and Analytics to reflect the assessment of the streets, blocks, zip codes, and city as a whole. It has management functionality for admin to manage the system. Various backend service like database and monitoring runs to monitor the system. It also has a detection engine, which is a machine learning based analytical engine running visual recognition algorithm to classify the images for cleanliness levels. These services designed to be highly available and visible to city admins and truck drivers and other users.

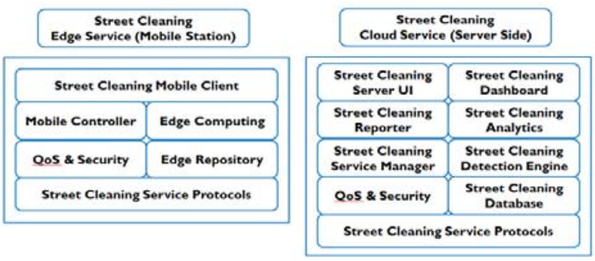

Figure 8: Detailed Systems Architecture.

B. *Detailed Architecture*

Architectures with all modules are described below. Figure 8 shows all the components with every submodule we have.

1) *Mobile Station Controller*

This component controls the functionality of the mobile station. It is a specialized device mounted on every mobile truck and manages the services like connectivity to cloud, compute resources, local storage, monitoring, and security. It notifies the city admin for any alerts or issues with the mobile station. It enables the camera to take pictures, store them locally and transmit them using the wireless network to cloud.

2) *Street Cleaning UI*

Cloud user interface offers services to users who can view the current status of streets or blocks. City admin can view the status of mobile stations. Cleaning dispatch can be made using this interface and feedbacks received can be handled from the same view. System performance and alerts are also managed from UI by respective city admins. This UI is linked to the database and all events are logged. City admin can manage users like user registration, approvals, and access control. All system alerts and any feedback received can be acknowledged from this same view.

3) *Street Cleaning Dashboard*

Cleaning dashboard is the module where the status of the entire system is visible to city admin. This includes cleanliness status in grid view, on street basis. Mobile station status is monitored from the same interface.

There is a submodule known as Street Cleaning Detection Engine with two subcomponents names Street Cleaning Analytics and Metrics, which are an external system. Our project when integrated with this external system would enable getting image processed for cleanliness level. This also includes database services for various engines and API end-points, which are being monitored from this dashboard along with system performance.

4) *Street Cleaning Service Protocols*

Service protocol refers to the inter-connectivity between various components of the system. This connectivity enables the data flow from mobile station to end users. It connects all mobile stations via wireless protocols including Mobile networks like 4G or LTE or city Wi-Fi. This layer also handles communication between various components of the cloud from application to database to detection engine.

Mobile Stations are connected to cloud services over the Internet, which rely on the wireless or Wi-Fi network. 4G or better connectivity is required for real-time communication. As soon as mobile station starts, it makes various network connectivity checks. Once connectivity is established, TCP connections are established between a mobile station and cloud services. Custom ports are used for secure communications.

Service Requests are handled on cloud services and use secure TCP protocol. It also uses authentication for each mobile station. Every mobile station is uniquely identified using a combination of use rid and mobile station id. It can be further enhanced at camera level.
DB connection control mechanism handles the connections to a database. In our case, most of the connections are made from cloud service for mobile and the application service. All DB connection is made over TCP and is authenticated. For security reason, we have kept DB services on a separate instance and it also decouples the app from database layer and gives the flexibility. UI connection modules are plugged into the web application service. Users are authenticated using a common separate database over TCP.

V IMPLEMENTATION

An attempt is made to simulate the end-to-end functionality using a mobile app, cloud service and a UI. Machine Learning is an external module. Mobile stations (MS) are connected via mobile network preferred 4G/LTE. Testing is done by creating a mobile app. MS would be specialized devices with the specifications provided by a city.

A. Use case:

Data is collected at mobile stations and then fed to a database in cloud for analysis and modeling. We created a mobile app to simulate same and collected actual data in San Jose city. This app at start performs checks like Network connectivity, Storage space on device and connectivity to cloud service. If any of the check fails it can report to administrator via email or SMS (text) to predefined contact. Data collected can be transmitted to cloud in real time or offline depending on network connectivity.
Certain assumptions were made to perform test. All images collected are transferred to cloud based database and then fed to machine learning for analysis. Data can be downloaded manually in case network connectivity is not available.
On the cloud side, data receiving application service run continuously which is used by all mobile stations. Images are stored on filesystem and metadata is stored in database for each image. We used AWS (Amazon Web Services)[11] cloud service to simulate the cloud connectivity and able to transmit data from mobile to cloud and update database. APIs are used to connect to machine learning module to get the result on each photo.
Application service connects to machine learning system and to the font-end database. NoSQL[12] and MySQL based databases are used to store and manage the data. NoSQL database would be used to have a detailed analysis and would be recording the fine details of each picture with assessment level. This would also be the base of all historic data and feed the trends and decision making for future. MySQL would be a backend database for the dashboards.
User dashboards are created for city and residents. This also has an admin module which can be integrated with other city systems like weather, traffic or dispatch. Residents can also view the latest activities on the street cleaning and can contribute as a feedback or suggestions.

B. Analysis – Point Level

Point level analysis is the core and the granular level of assessment. This is the key for entire system. Below are the attributes of the point analysis. At least four pictures are taken at every point. Two points distance is customizable by admin and will be defined as part of the configuration. From the experiences, we have taken 20Ft. as a distance based on the speed limits. Pictures will be sent to the cloud along with meta-data i.e. date, time, location, image path. Log information will be stored on device periodically. Each point will be represented in a different color to indicate the level cleanliness level. Figure 9 shows an example point level analysis, where a figure is shown in four pictures, left, front, right and back. If there are litters in these pictures, they can be caught by these pictures for analysis.

Figure 9: Picture Point.

C. Analysis – Street Level

From each point on a street between start (S) and end (E) points, all numbers would be averaged to generate an overall assessment of the street. The assessment would be done for every street. Results are stored in DB with image reference, date time and level. Each street is a part of one block. Grid based analysis and part of the block. Figure 10 is an example of street level analysis.

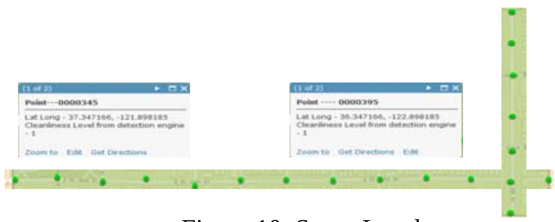

Figure 10: Street Level

D. Analysis – Block Level

It is an aggregate of all the points on the block. Block Assessment Value is an aggregate value of all streets. The assessment would be based on every street in the block and the aggregate value. Results are stored in DB with image reference, date time and level. Block can have any number of streets. Everything is based on each data points. Figure 11 is an example of block level analysis.

Figure 11: Block Level Analysis

E. Analysis – Area level

Based on the block level analysis, area level analysis can also be performed. Figure 12 is an example of area level analysis. Area is a combination of many blocks with different colors.

Figure 12: Area Level Analysis

VI CONCLUSION

In order for a city to become a smart city, infrastructure needs to be upgraded to next level. A clean city is the essential component and reflects the image of the city for residents and visitors. This system can also be well integrated with other city systems like traffic, weather etc. Residents can also contribute and help city using this system by providing feedback and by reporting any issues identified by them. This system can be implemented by any city and in fact, this can act as one big system as a grid of cities. Security and access can be controlled by individual city administrators.

VII ACKNOWLEDGMENT

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