

CE-791

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Pipe Overflow Prediction Model in Stormwater Networks and Visualization Using Mixed Reality

# Abstract

**Objective**: The main objective of this paper is to predict overflows in stormwater networks using smart cities technologies and data-driven models and improve collaboration between utility managers and technicians using smart visualization techniques.  
**Methods**: In order to achieve better communication and visualization for utility mangers and develop overflow prediction models, the researchers in this paper used digital twin models in a Mixed Reality (MR) environment which is connected to a real-time overflow prediction model based on forecasted precipitation or rainfall hydrograph.  
**Results**: The results of this paper indicate that it is possible to predict pipe overflows in stormwater networks using neural networks with a very high accuracy and connect that model to a MR environment in a 3D engine.  
**Conclusion**: The prediction model which is proposed by the researchers in this paper can improve the efficiency in stormwater management systems and help utility managers in hard decision making processes and improve their performance during disasters.

Keywords: Mixed Reality; Smart Cities; Digital Twin Model; Artificial Neural Network (ANN); Overflows prediction model

# 1. Introduction

**One of the new and growing technologies in the U.S. and all over the world is smart city technologies. The smart cities technologies can save over $5 trillion for enterprises, governments, and citizens annually over the world (Ismail 2017). For example there is a $14 billion saving opportunity for enterprises in areas like more efficient transportation options such as drones, robots or driverless cars and trucks and there is a $5 billion annual saving opportunity for governments using street lighting and smart building technologies. Using smart street lights it is expected to reduce repair and maintenance costs by 30 percent. It is possible to utilize smart city technologies in new areas in order to achieve more savings.**

Many researcher tried to utilize smart cities technologies to achieve more savings in different areas like smart transportation, smart infrastructure, smart Disaster Management System (DMS), and smart visualization. Two areas that still need more developments are smart DMS and smart visualization. Many researchers tried to develop emergency response system in order to reduce costs during a disaster (Alazawi et al. 2014), but still there is a big gap between other sections of smart cities and smart DMS. Furthermore, smart visualization technologies can help utility managers to reduce costs as well. (Data, Life, and Better 2017)

Overflow in wastewater and storm water networks is one of the old problems of big cities with old networks. Especially in cities like Chicago because of old combined sewer networks.(Jim Gudas 2018) Detection of these overflows and the reasons behind might be very helpful in post and pre disaster responses, improve the quality of citizens’ life, and help to achieve smart cities ideas.

Besides, it is very important for future smart cities to have smart visualization. “Smart visualization is the first step toward becoming a truly smart city” (Data, Life, and Better 2017). Without proper visualization it is almost impossible to achieve smart cities so smart visualization is the key to achieve smart cities and give utility manager better understanding about their cities. This smart visualization can help the managers to make better decisions and more efficient management during disasters.

The researchers in this paper tried to develop a real-time overflow prediction model based on the forecasted rainfall hydrograph for city of Raleigh and utilize smart visualization techniques by development of a MR-based twin model. They used different ANN models to achieve best real-time prediction model for overflow prediction with reasonable error.

# 2. Literature Review

## 2.1 Pipe overflow problems

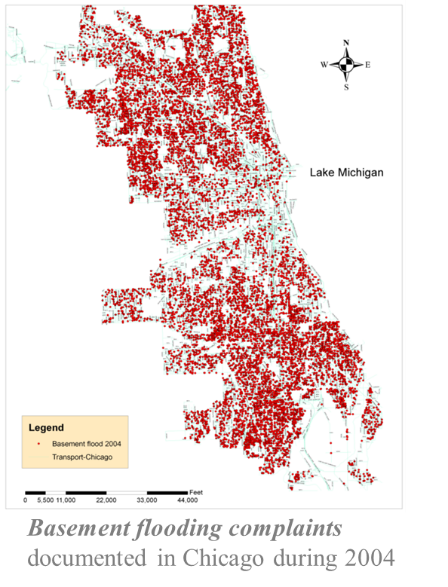


Figure 1: basement flooding complaints documented in Chicago during 2004

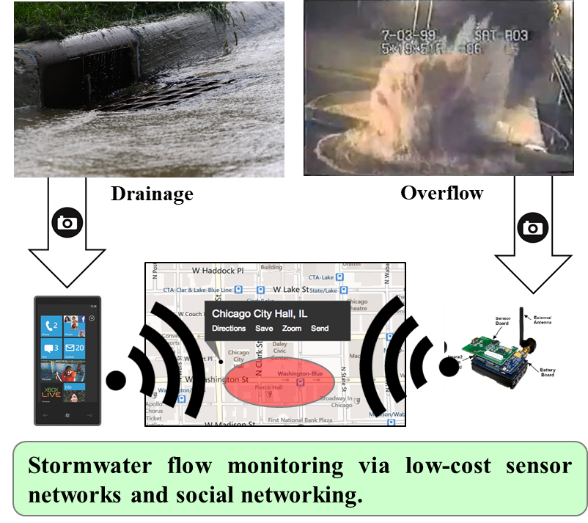


Figure 2: stormwater flow monitoring via low-cost sensor networks and social networking

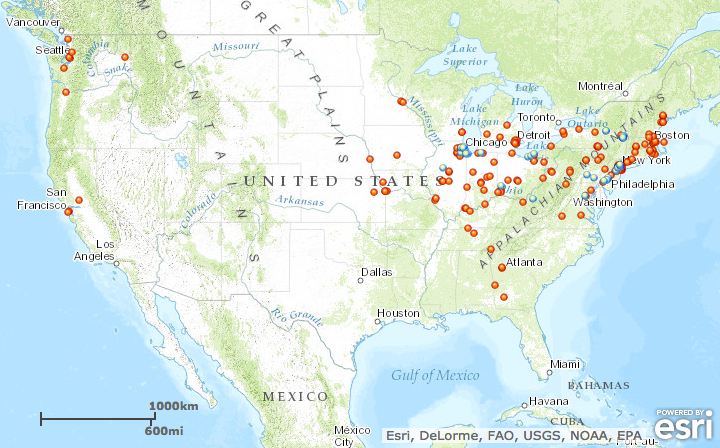


Figure 3: overflow problems across the United States

## 2.2 Data visualization challenges

1. Multidimensional data (e.g., vehicular traffic data) cannot be probed effectively from different aspects (such as "when was traffic data highest" or "How is it related to weather?,"etc.) on a flat screen. To understand their different relations with other data, you need to run analysis multiple times. You, often, forget the previous relations or you do not get a complete picture of a situation simultaneously.

2. The current analysis and visualization platforms do encourage collaboration as stakeholders from different departments such as water and waste management departments from remote locations cannot see and interact the same data simultaneously. Today, cities move by data. Government agencies prevent unwanted incidents, warns citizens beforehand any eventualities and protect those using real-time data insights. Any inefficiencies to handle data not only make the smart cities ineffective but also pose severe risks to citizens’ lives.

3. Imagine there is a leakage with a pipeline at some point. A new engineer goes there and want to dig the ground. He must rely on a 2D static map without any detailed information of equipment installed underneath. He needs to rely on voice-based Instructions from his senior. Though the sensor captures all information about the pipeline, the current platform fails to disseminate critical information to remote workers.

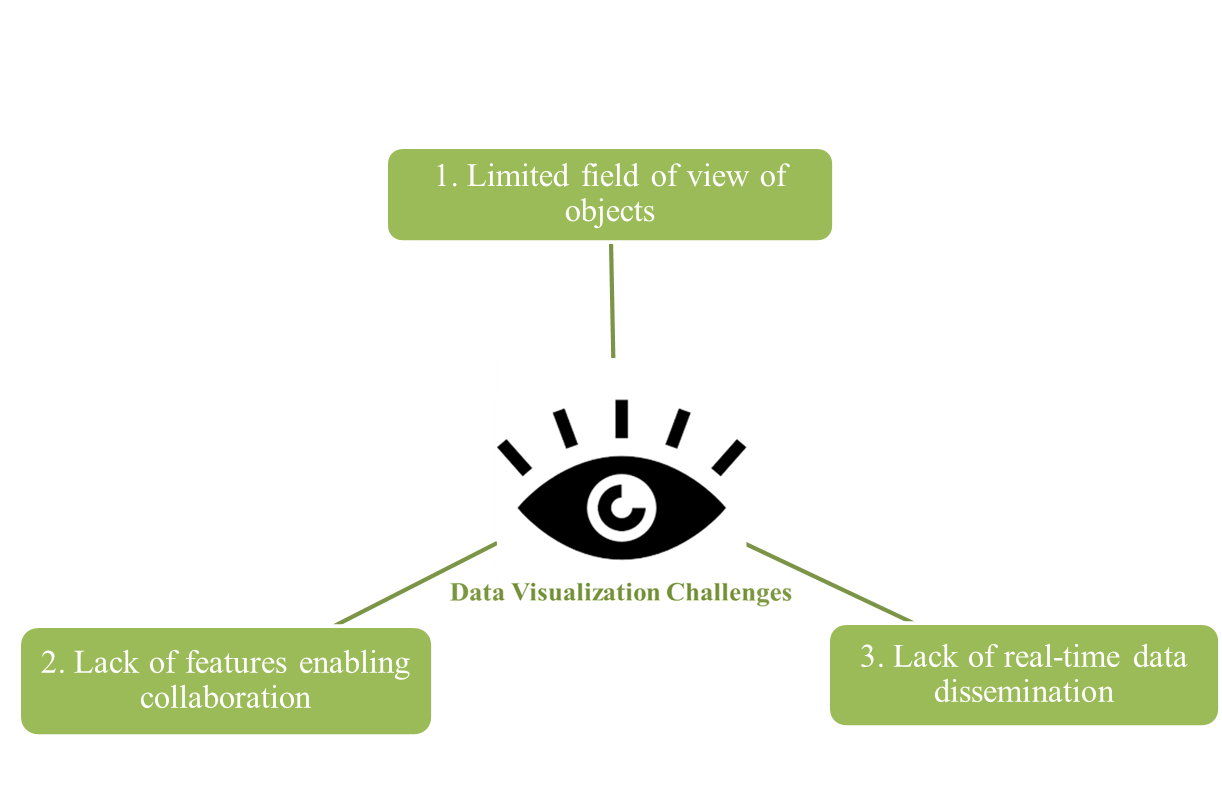


Figure 4: Main data visualization challenges

## 2.3 MR in civil and smart cities industry and other industries

//Digital twin technology

The concept of digital twin introduced around 2002 and by improving technologies like Internet of Things (IoT), this concept has become more cost-effective to implement and can create more opportunities for cost savings. (Bernard Marr 2017) Furthermore this technology named as one of the top 10 strategic trends for 2017 by Gartner.(Kasey Panetta 2016)



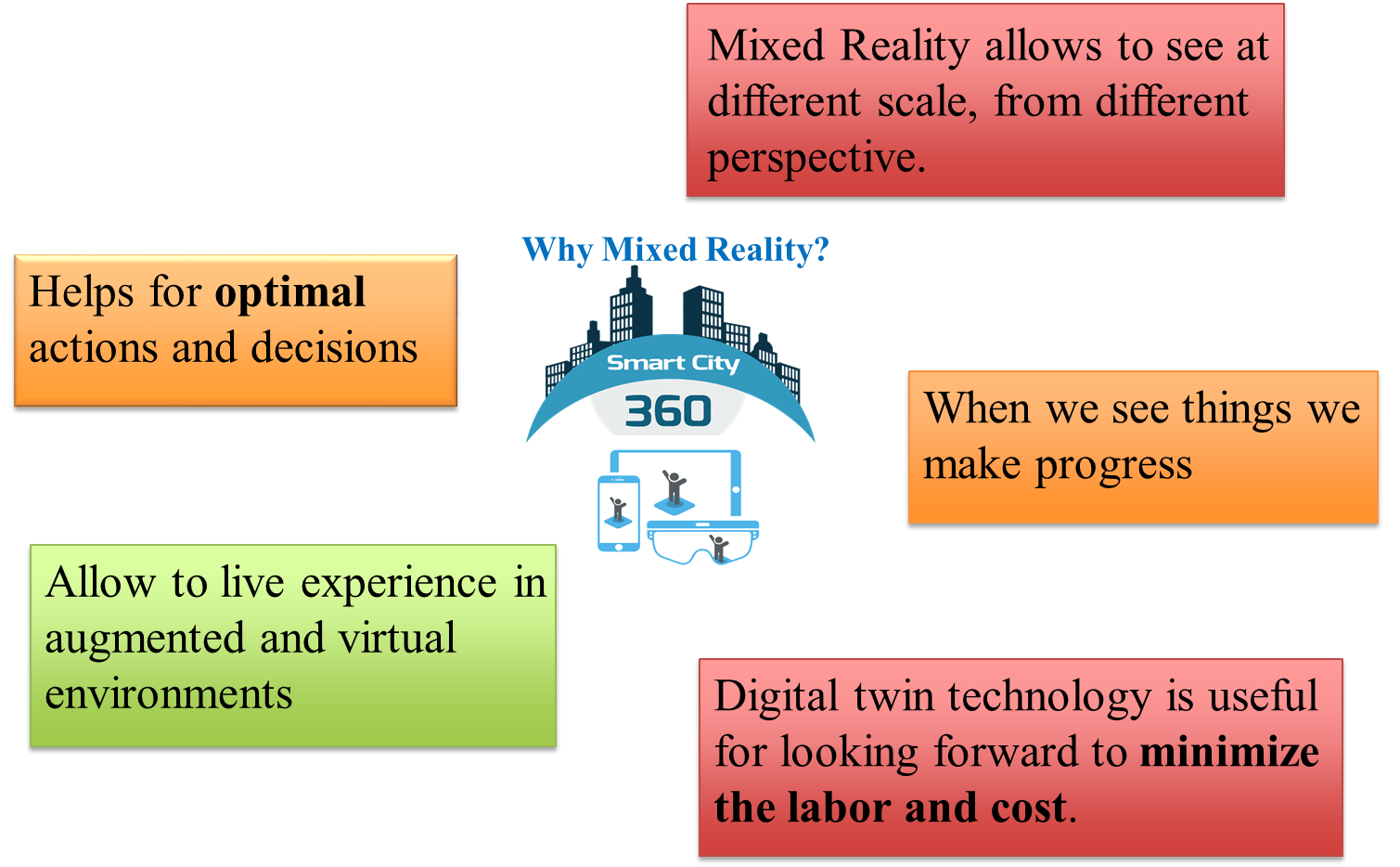


Figure 5: main reasons for using MR as a better approach for visualization

# 3. Research Objectives

The main objectives of this study is to predict pipe overflow problems in Stormwater networks and create a MR digital twin in order to improve visualization and communication between utility managers.

1. Create a platform to predict overflows in order to help utility managers before disasters
2. Create a digital twin for the Stormwater network and enable utility managers for better decision making using Mixed Reality technology

# 4. Method

In order to achieve the objectives, the researchers in this paper used the following approach. At the beginning the researchers 1) gathered the overflow data from Storm Water Management Models (SWMM) for the city of Raleigh. After that the researchers 2) created an artificial neural network model in order to predict overflow positions based on the SWMM data. Finally, the researchers 3) visualized the overflow problems in a MR environment in order to achieve better visualization and collaboration for utility managers.

1. Generate data from SWMM
2. Create models for predicting overflows
3. Visualize in a twin MR model

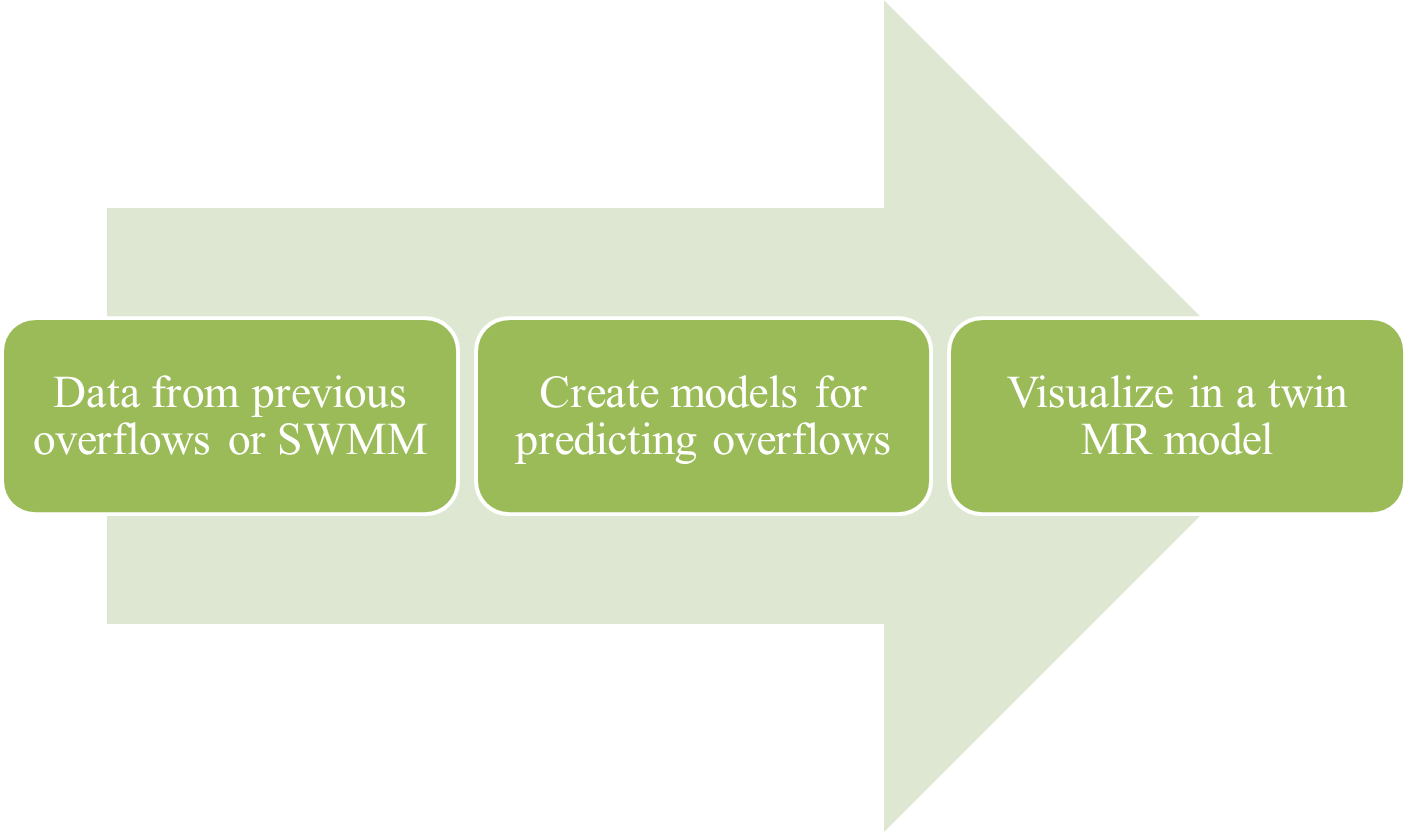


Figure 6: research method main steps

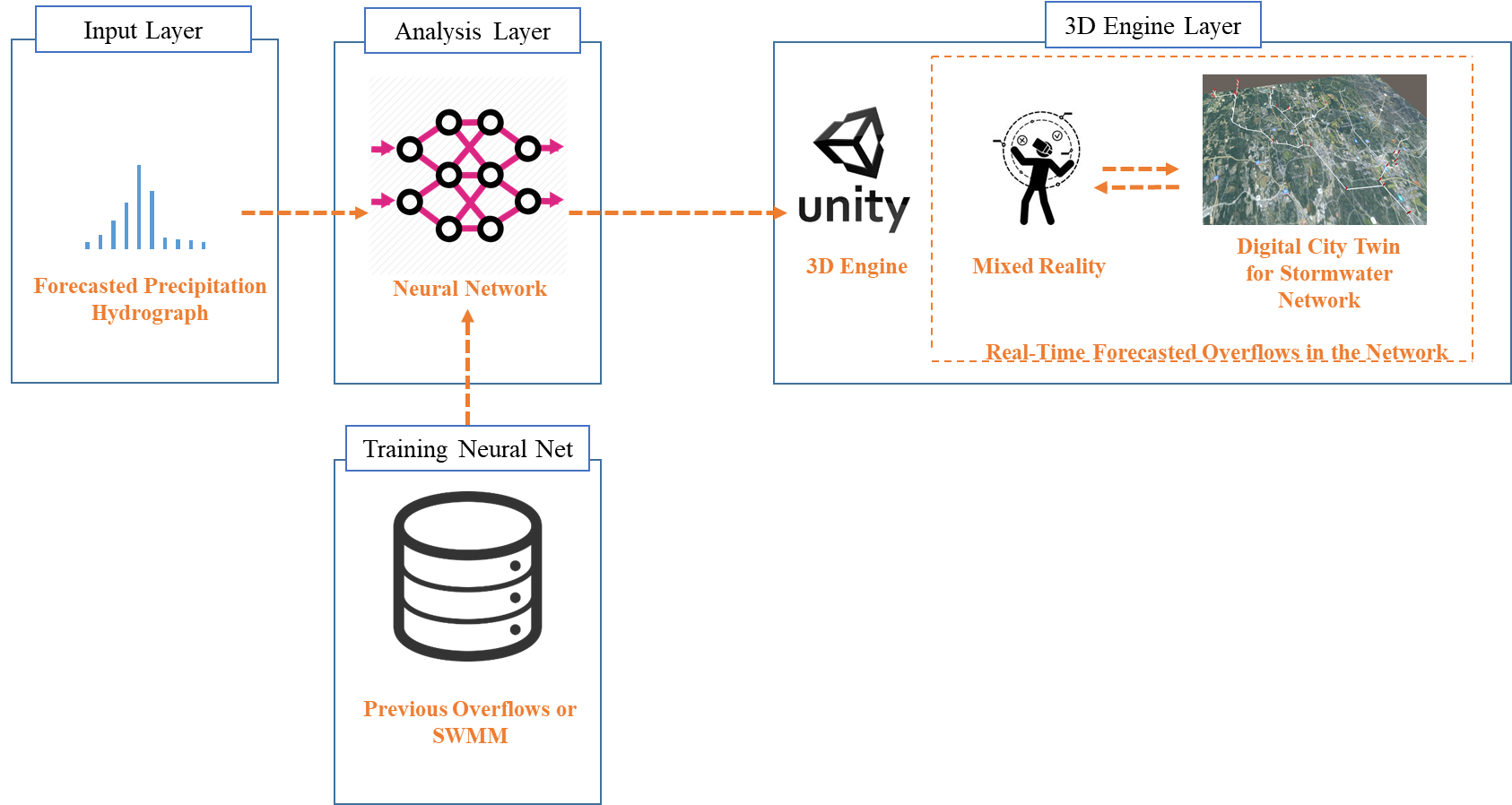


Figure 7: system architecture which represents the prediction model and MR

The system architecture consists of three different layers. These layers are as follows:

**Input layer:**

As input of the prediction model, researchers in this paper used forecasted rainfall hydrograph. The main factor and reason for overflow in stormwater networks is rainfall with big peak. The reason behind is when there is a high peak in rainfall hydrograph, the load on stormwater network is high and the level of water increase significantly inside the pipes which lead to overflows and flooding of the network.

**Analysis layer:**

**3D engine layer:**

## 4.1 Pipe overflow prediction model

In the following section, the researchers will introduce the data which is used to train neural network and the specifications of the neural network which was used.

### 4.1.1 Data from previous overflows or SWMM

Input data for the prediction model extracted from city of Raleigh SWMM. The researcher in this paper gave 150 different rainfall hydrograph with 5 minute sampling rate to SWMM and find the pipes with overflow problems from SWMM analysis. The output data was the volume of the surcharge so the researchers annotated that data in the following way. The pipes which have overflow problems are 1 and the pipes with no overflow problems are 0. A map of Raleigh stormwater network and a 5 minute sampling hydrograph are demonstrated in the figure 8.

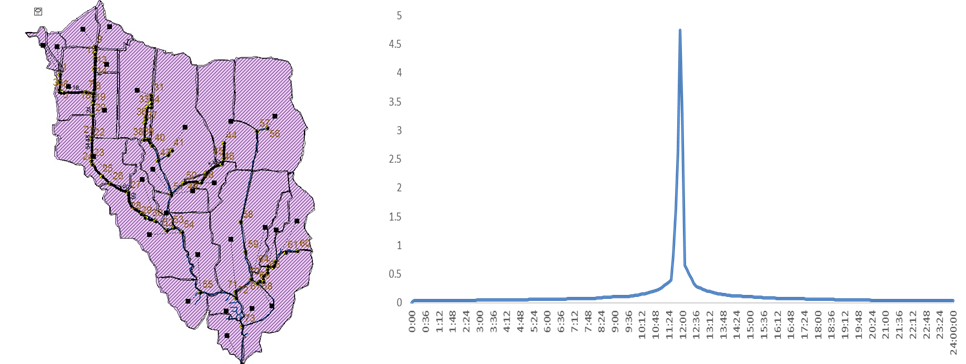


Figure 8: Raleigh stormwater network map on left and sample precipitation hydrograph on right

The 5 minute sampling rainfall hydrograph has a very high dimensionality. It is very important to decrease this dimensionality, otherwise it is very important to increase database significantly. It is very hard to increase database size so the researchers tried to decrease the dimensionality by feature extraction technique. The researchers picked 4 different variables to identify each hydrograph. This approach reduce dimensionality significantly and reduce required data point in the database. Variables are listed as follows:

1. Variable 1: first report in rainfall hydrograph which is more than one inch per minute. This variable shows the gradient of the beginning of rainfall indirectly. The following formula demonstrates the direct relationship between variable 1 and the gradient.
2. Variable 2: highest point in the rainfall hydrograph is the second important variable. As aforementioned earlier this variable has a direct relationship with the overflow problems in storm water networks.
3. Variable 3: last report in rainfall hydrograph which is more than one inch per minute. This variable shows the gradient of the rainfall end indirectly. The following formula demonstrates the direct relationship between variable 3 and the gradient.
4. Variable 4: this variable shows the duration of rainfall between variable 1 and variable 3. This duration shows the rainfall and it can have an important impact on the overflow problems.

Four different variables are demonstrated in the figure 9.



Figure 9: four variables which represent a hydrograph

In addition to decreasing dimensionality, it is very important to have a good variation in the database so neural network algorithm can predict different circumstances correctly. The database has four different inputs, it is not possible to draw these four inputs in a chart, but in order to show that the database has enough different data, the researchers picked 3 first variables and draw in on a chart. The figure 10 demonstrates the input data distribution over the space. This chart shows that there is a good distribution of input data in the database so this database can be used for a good prediction.

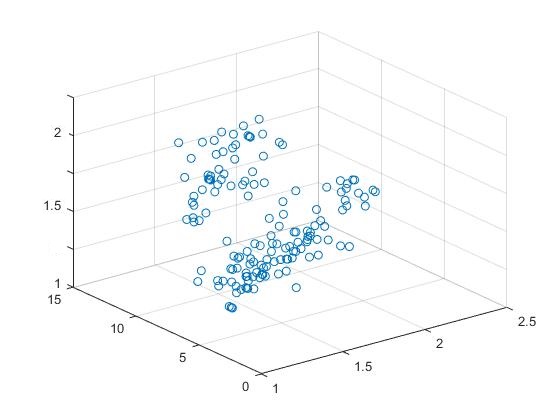


Figure 10: input data distribution

### 4.1.2 Develop neural network models for overflow prediction

The researcher in this paper used different neural network models and get the best result with neural net fitting approach. The researchers used a neural network with the following specifications.

The neural network consists of 4 input variables as main parameters of a precipitation hydrograph, 3 hidden layers, and 73 outputs which represent 73 junctions in the network. The output values are either zero or one which means flooded or not flooded.



Figure 11: neural network overview

The researcher used 70 percent of total data for training, 15 percent of the data for validation, and 15 percent of the data for test.

### 4.1.3 Data analysis

// investigate the main 3 factors

As a digest of aforementioned hypotheses. The main limitations of VR/AR utilization in construction industry is lack of budget, lack of understanding of upper management, and lack of knowledge of design teams. Finding a solution for these limitation can simply improve VR utilization and customer satisfaction rate.

## 4.2 MR digital twin model

It is possible to use VR models for different purposes in construction like

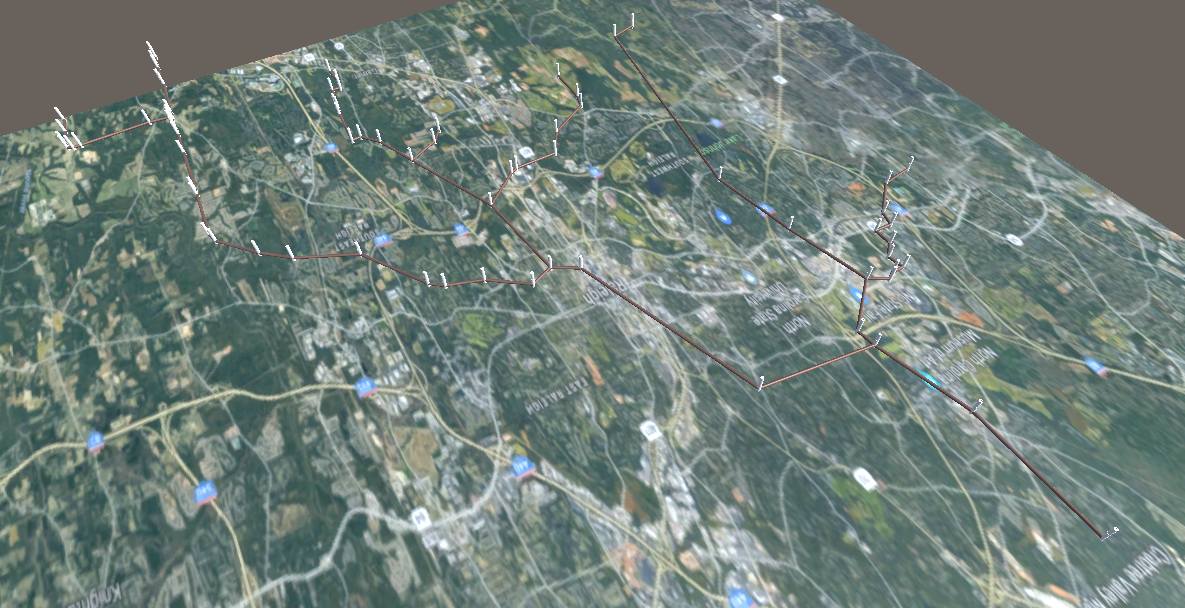


Figure 11: digital twin model of Raleigh stormwater network in MR environment

### 4.2.1 Procedure

// Flow

# 5. Results and Validations

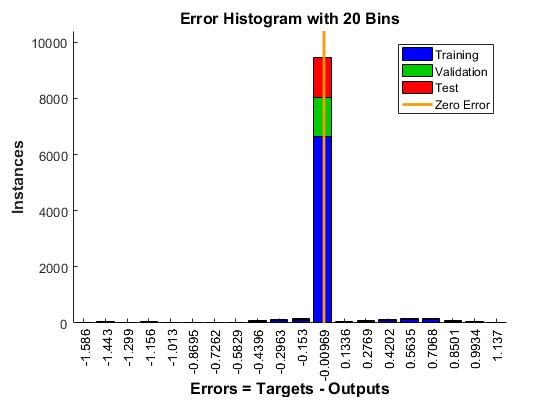


Figure 12: error histogram for the trained neural network

* Real-time over flow prediction platform
* Test a totally new sample with just one misclassification
* The results of this study shows how we can use data collected by sensors to improve management and predict overflows.

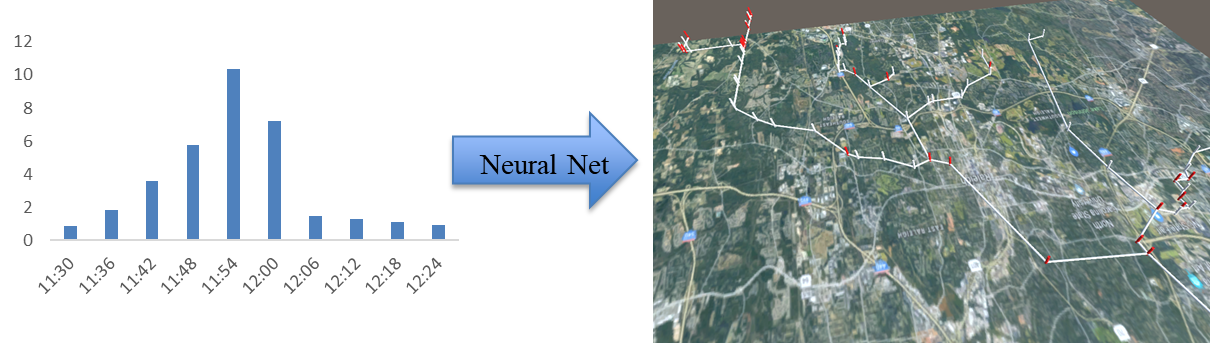


Figure 13: real-time MR environment which can predict overflows and show them by red color

// IMAGE FOR THE MR

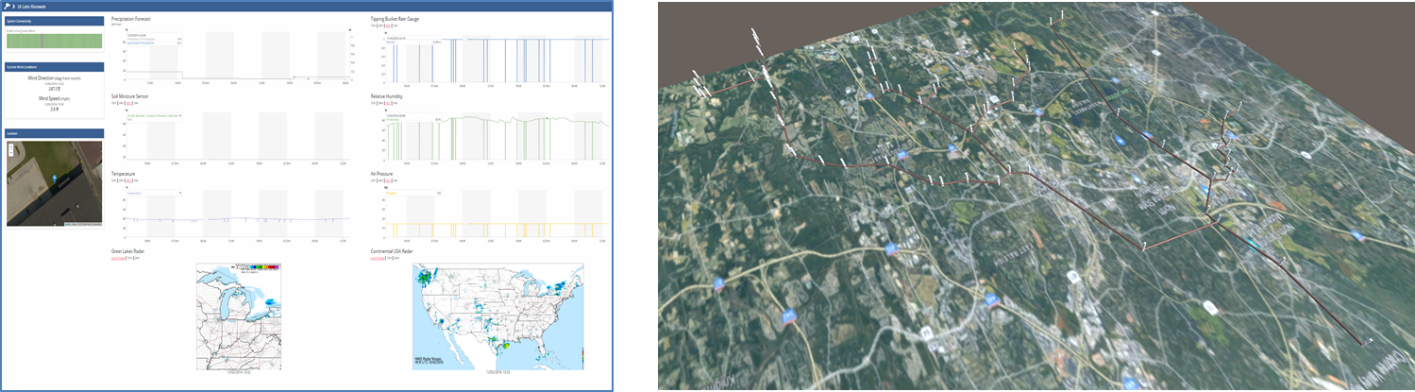


Figure 14: transition from old smart city dashboard into the new MR digital twin model

# 6. Limitations and Future works

## 6.1 Limitations

One of the main limitations of the overflow prediction models is that it cannot detect issues caused by extraordinary events. For instance, if a tree falls into one the conduits in the network, the prediction model cannot predict the upstream overflow for that specific conduit and it may give you false results for the downstream of that pipe.

In addition to the first limitation, this platform cannot give you any recommendation during a disaster. For example if you have 5 teams of technicians that can solve overflow problems and there are 10 different overflow locations, how you can prioritize the overflows. So in these occasions, the utility managers should make a decision based on their experience and the real-time platform cannot help them in decision making process in post and pre disaster responses.

## 6.2 Future works

It is possible to connect several MR devices in order to have a multiplayer experience for utility manager. For instance if one of the managers changes something in the stormwater network, all of the utility managers and technicians can see that change simultaneously. This improvement can cause better communication and collaboration between utility mangers and technicians.

For this paper researchers used data which is generated by SWMM, but it is possible to use previous overflow data in order to achieve more realistic results. The reason behind is using real data can give you better information because the real network might be slightly different from SWMM or even some part of the network might be changed over time.

In order to improve digital twin technology it is possible to combine current stormwater twin models in smart city models. And even generating twin models for other infrastructures like water network, electric network, and gas networks. Having a digital twin model which contains all of the data related to the networks can give utility mangers better visualization and help them in decision making process.

# 7. Conclusion

The problem which was represented in this paper was to predict overflows in stormwater networks and improve the visualization and collaboration using smart visualization techniques. The proposed platform in this paper is able to predict the overflows in stormwater networks based on predicted rainfall hydrograph and visualize the results in a real-time MR environment for better visualization and collaboration. This platform can improve efficiency in stormwater management systems and give the utility manger ability to have a rapid and ahead of time response in emergencies and disasters which can lead to efficient disaster management.

The researchers in this paper used different neural network approaches to predict overflows and represented the best results with highest accuracy. This model is able to predict the overflows with high accuracy in real-time.

# 8. References

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