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Data Mining And Artificial Intelligence In Water Supply Management System

Analysis using Apriori Algorithm

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Abstract: This paper discusses about the data driven intelligence role in managing the water resources, pipelines, infrastructures, geographical and environmental conditions required for the urban water supply using information technology like Data Mining. Implementation and maintenance of the uninterrupted water supply system using Artificial Intelligence with the help of building the Data Warehouse. Focus on use cases related to solutions for the challenges in water supply management in the urban areas due to fast growing and dynamically changing inhabitation to meet the required quantity without compromise in quality considering cost indices.

Optimizing the productivity and strengthening the information management is the main driving force to improve the ability to sustain the requirement, this can be achieved using GIS in Data Mining to gather the information, Data Warehouse technologies to store the data in organized way, implementation and maintenance using Artificial Intelligence technology.

Index Terms - Data Mining, Data Warehouse, Water Supply Management, Artificial Intelligence.

I. INTRODUCTION

Applying of data mining and data warehouse technology in operating the water network efficiently by monitoring and controlling the network assets, such as valves and pumps to reduce the unaccounted-for-water problems and improving utilization ratio of the water. Use of Artificial Intelligence (AI) technology to optimize water network performance in terms of water pressure and quality. This paper also discusses about how Apriori algorithm in Data Mining is used to generate strong association rule and helps in making complex decisions.

Artificial Intelligence technology utilizes the data from the data warehouse to analyze the network data and patterns in real time to control networks from water resources, reservoirs to end user tap which results in increasing process efficiency in terms of operations and energy. Use of sensors and IoT technologies in AI and Machine learning, research and development in data analytics and mining has increased the resolution and granularity of data required for computation and building adaptive feedback system. AI and Machine learning algorithms, fast processors, sensors, Real Time Operating Systems can compute the high-resolution data and provide output required to control the network assets such as valves, pumps, pressure monitoring and control system, direction controls and pipeline conditions. AI has predicting, forecasting and prescription capabilities using advance tools along with the computation based on historical data.

AI applies the advanced algorithms like artificial neural networks in image processing, sound recognitions and Analog-to-Digital data conversion to analyze the various data in the water network continuously and providing probabilistic calibration to understand the structure of the errors at each point like valves, pressure gauges, pipeline joints, water reservoirs, routers, filter points and pumping facilities. This data-driven approach helps in integration of data from various sources, smart visualization, and trend forecasting for business intelligence. Provides human resource management, collaborative and knowledge sharing platform, E-learning platform for knowledge management. AI tools, platforms and databases are fully compliant with cybersecurity laws and techniques as data related to water is critical asset in terms of public health, infrastructure protection, finance, and business.

II. DM AND AI BASED WATER SUPPLY MANAGEMENT SYSTEM

The proposed system consists of following five subsystems such as 1. GIS and Sensors, 2. Real Time Data Concentrator and Integrator System (DCIS), 2. Data Warehouse, 3. Embedded Display Processing System which embodies other subsystems like Data Mining (DM) System, Artificial Intelligent (AI) System, Control and Dispatch System and 4. Broadcast and Wireless system.

The functional structure of the system can be divided into three parts: 1. Central management system, 2. Wireless communication net and 3. Enterprise subnet system.

1) GIS AND SENSORS

Geographical Information System (GIS) is a software platform provides information related to pipelines, pipe length, pipe diameter, pipe roughness coefficient, water supply pipeline network and associated assets like valves, pressure gauges etc. which are derived from Environmental Protection and Network Evaluation Tool (EPANET) model.

GIS and Sensors receives water supply and consumption real time data from Supervisory Control and Data Acquisition (SCADA) monitoring nodes for processing in the Electronic Control Units (ECU) which are also called Programmable Logic Controls (PLC) or Remote Telemetry Unit (RTU).

ArcGIS Engine customized for geographic processing and water supply management system is used in water supply network design and simplification based on real time data. Libraries in the ArcGIS Engine supports the mapping, database connections, control licenses, provides co-ordinate system data and interoperability [6].

2) DATA CONCENTRATOR AND INTEGRATOR SYSTEM (DCIS)

The Real Time Data Concentrator and Integrator System (DCIS) receives input data from the ECU for different parameters monitoring and detection systems like Leakage Detector Unit, Pipeline Network Monitor Unit, Valve Monitor Unit, Water Pressure Monitor Unit, Water Source Monitor Unit and Water Quality Monitor Unit.

The water supply network is huge, complicated, integrated and dynamically changing so collecting and monitoring the data and assets are difficult [7]. The wireless sensor networks installed at different network asset points are connected to ECUs for the corresponding parameters makes the monitoring of assets simpler. ECUs detect and monitors the real time data from water resources, pipeline networks, valves and other water supply network assets through SCADA and GIS and process and validate the data before sending this to DCIS [6]. The processed data from the ECU consists of parameters related value, status, commands, and block of data related to water network parameters like position of valve, any leakage in the network, water resources status, quality of water and location of issue w.r.t time co-ordinate, position co-ordinate and reference co-ordinate.

DCIS consists of Input/output mapping table, Integrators, segregators, Analog-To-Digital Converters, mathematical model, and frequency mapper to sample the data speed down/up. All processed data from the ECUs are filtered and integrated before sending to Data Warehouse for storage and analysis. In this way DCIS plays important role in Data Driven approach by establishing network between water supply infrastructure, integrating, and monitoring of sensor data through ECUs, data warehouse and information management system to effectively organize and co-ordinate every subsystem [8].

3) DATA WAREHOUSE

The data warehouse is the main integrity of the data mining and Artificial Intelligence based water supply management system [1][2]. Data warehouse stores organized and processed data to provide Information Integration platform based on the data which have been transformed, conditioned, and integrated, and received from Data Concentrator and Integrator Systems (DCIS). Data warehouse is used for the Online Analytical Processing (OLAP). The results are used in Measurement and Management System of Water quality, Water Pipe Networks GIS, Water Charge Management System, Cost index, Human Resource System, Pipe Network MIS, Office Information System, Pipeline/Valve leakage, and Pipeline Pressure Monitoring. It provides data for infrastructure extension, customer relation, costing, management, management of water quality. Refer the Data Warehouse system in the figure1 related to DM and AI based Water Supply Management System.

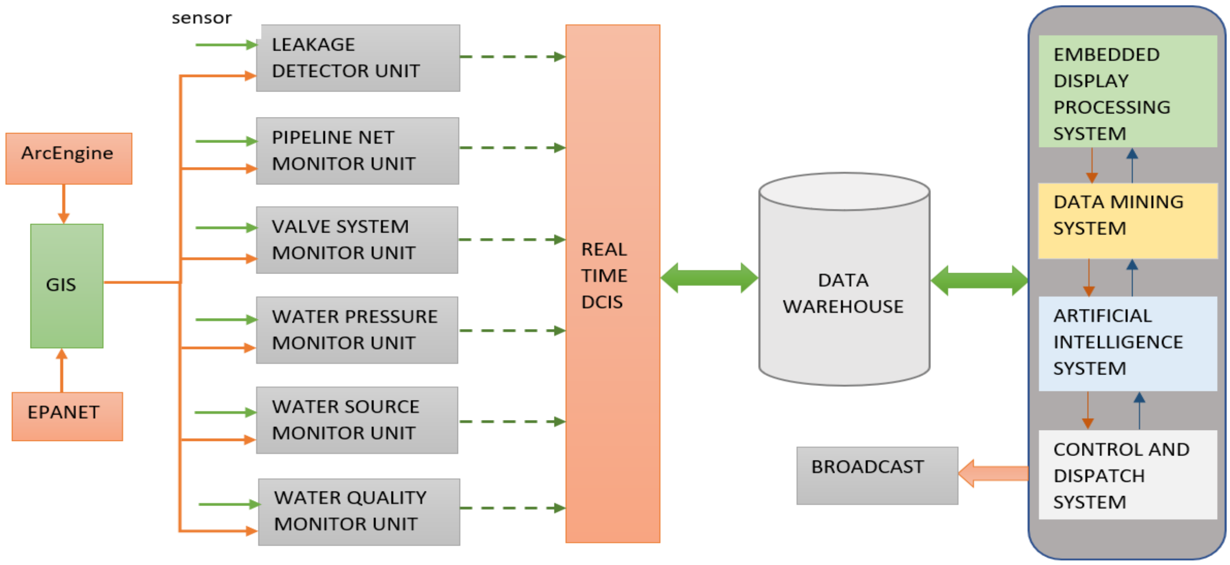

Figure 1: DM and AI based Water Supply Management System block diagram.

The Data warehouse is multidimensional database consists of different dimensions related to time, customer, geographic, monitor instruments, location sensors and detection sensors. It will also provide high resolution granularity for each dimension imported from the GIS.

Data Warehouse system acts as central management system by getting data from ECUs through DCIS, monitoring data of the related parameters of water supply network asset and online analysis of the data reliability, validity, and integrity of interface modules.

Real Time Monitoring: It manages data of all kinds of water network asset, has the functions of input, saving, recognizing, inquiring, and transporting monitoring data, integrated manages and processes the monitoring data and shows the output in the ways of chart and simulation data using data from GIS and EPANET.

Real Time Dispatching: It can remotely control the water network asset to the real time collected local data and the arrangement of resource.

Integrated analysis and decision-making support: It analyze processes and disposes the real time data of the system to analyze and forecasts the trend of the variety of water supply network assets scientifically using the scientific mathematical model, and dynamically outputs the result in the way of real time report.

Data warehouse, model base and repository: Data warehouse is the fundament of the operation of the whole system, and it saves lots of real time and complex monitoring data.

Math Model base supplies the processing model used by corresponding analysis and process and routine library of the computing method.

Repository saves info of management knowledge including like the monitoring index of the projects, the judging criterion of daily inspection, the limited error monitoring data, Index of special rules, the knowledge and experience of experts, laws and regulation, related item of calling rules and regulation.

4) *EMBEDDED DISPLAY AND PROCESSING SYSTEM*

This system consists of embodying of mainly four subsystems called Display and Processing System, Data Mining System, Artificial Intelligence System, Control and Dispatch System. Each subsystem running on different partitions on different computing processers, and each will cross talk through Inter Process Communication protocols.

a. *Display and Processing System*

This display and processing system runs on the Partition OS on the PowerPC based computing model. This system will provide a platform to launch the DM and AI tools and GUI for different controls and Multifunction. This system crosstalk with other three subsystems like Data Mining System, Artificial Intelligence System, Control and Dispatch System.

b. *Data Mining System*

The Data Mining Engine and associated Pattern Evaluation module is running on partition OS running on another computing module. Data Mining tools running on this platform fetches the data from the Data Warehouse and extracting the data to process, engineering analysis and provides computed results by cleaning, transforming, and pattern evaluation [3]. Data mining tools such as SAS (Statistical Analysis System), Orange Data Mining etc. predict behaviors and future trends, allowing businesses to make proactive, knowledge-driven decisions. Business related questions are resolved with the help of tools in less time and human effort ex: - Apriori algorithm. Also, tool will use mathematical queries as per the databases patterns and structure to extract the data and generates all predictive analysis results with graphs and reports used by domain experts for evaluation and validation of the system status.

Data mining helps in searching required information in a large database. Which involves processes of moving, deleting, inserting, and sorting huge amount data, between tables, between memory intelligently using machine learning and artificial neural network algorithms with advance data structures and libraries.

Building of Data Mining module require knowledge of design, structure, modeling, and Input/Output of the system for example in this Water Supply Management system we need to have knowledge on following subsystems:

I. *Data Mining Model in Water conveyance*

Water conveyance model is created by calculating the flow of water from the water resources like reservoirs to the supply pipeline networks, which consists of branches, nodes, and storage junctions. Considering factors related to consumption, pipeline dimensions, valves, flow rates and leakages and damages, Model will be created based on historical data and time between finding failures and solving them, this will help to improve efficiency and save resources.

II. *Data mining model in maintenance of pipes net*

There are three models in maintenance of pipe network here: The Aging model, The Fragile Model, and The Accident model.

The Aging model based on the statistical analysis on history records of the maintenance of pipelines net whose main task is to analyse the relationship between the historical data of maintenance records and the pipeline net attributes of parameters.

The Fragile Model makes use of many attribute data as the data sources of statistical. There are many kinds of formula that have been used in calculating the different statistics items. The Fragile model contains many parameters. For example, the vulnerability of parameters includes the marina on the corrosion, pipeline corrosion protection, pipe, pipe laying area, whether at the state, such as immersion etc.

The Accident model makes the analysis of bottlenecks in pipelines net through space statistics and the association rules, when encountering certain pipeline incidents that may affect the water supply to the areas. Parameters include whether pipes connect hospitals, medical facilities, or water large areas. Through this model we can get the Optimum Plan of the path for maintenance according to Needs.

III. Data mining model in maintenance of valves net

The Valves distributed in the water network need to be constantly monitored, status and position of the valves need to be continuously measured and evaluated and controlled based on need. Also valves in the network need to be maintained based on three models Aging model, Fragile model, and Accident model.

IV. System portion function

Data Mining tools will calculate the service time of the pipelines network devices and network assets using related factors like damages, duration of project, topology analysis, history record and maintenance data imported from Data Warehouse.

Data Mining tools will also use feedback signals from the sensors, GIS, EPANET and SCADA data installed across water supply network to forecast the issues.

V. Optimization scheme

Make an optimization scheme combination of spatial data mining and daily water supply data.

c. Artificial Intelligence System

The artificial neural network algorithms in the AI system process the data from the Data Mining and Data Warehouse system and generate the output commands and controls to Control and Dispatch System to dispatch to broadcast system [4][5].

This AI System runs on the System-On Chip FPGA (SoC-FPGA) based computing module in which some of the applications running on the SoC PowerPC and SoC DSP like importing data, explore data and engineer features using mathematical models, Artificial Neural Network Algorithms and Models runs on the SoC GPU (Graphical Processing Units) and building the AI model and Health Monitoring (HM) on the Field Programmable Gate Array (FPGA). The inter process communication is established using Network-On Chip (NoC)

The below figure 2 shows the steps in Building Artificial intelligence or Machine learning system.

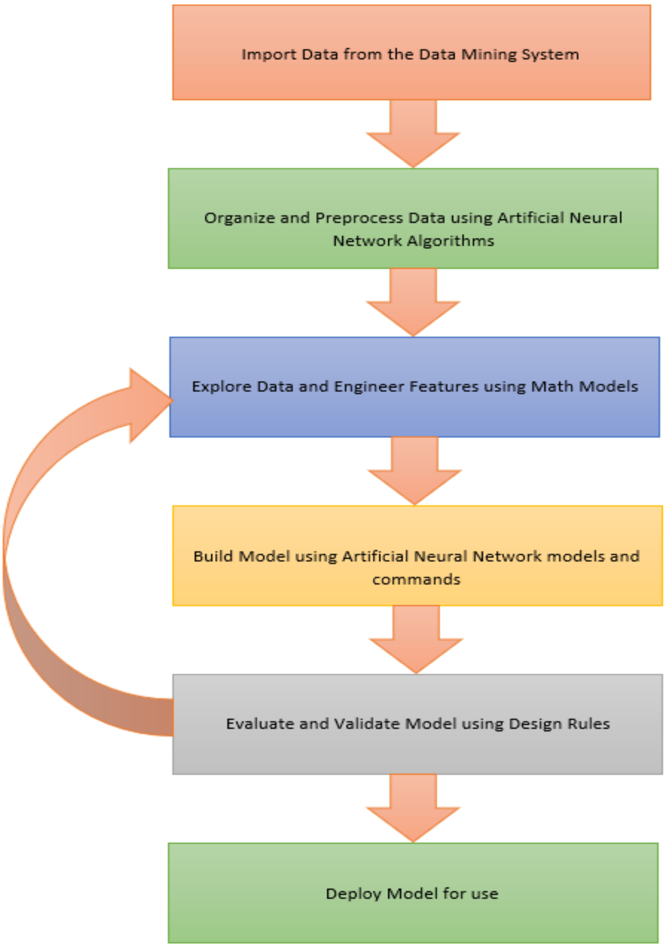

Figure 2: Steps to Build AI Model

The first step in AI subsystem is importing the data from the Data Mining Subsystem, followed by organizing and processing the data using artificial neural network algorithms. Processed data is used exploring engineering features against mathematical models and building AI model. Once AI model is built then it is evaluated and validated against design rules if there is any mismatch then again steps are iterated and re-build the AI model until it meets the design. Finally, AI model is deployed or configured to generate the commands, status and data required to maintain adaptive feedback system and send to Control and Dispatch system to pack the data and broadcast. AI process is based on heuristics and Machine Learning is based on both heuristics and statistics.

d. Control and Dispatch System

This system dispatches the commands, controls and data received from the AI, DM, and Display Processing systems to Broadcast systems to send data to remote networks areas.

5) BROADCAST AND WIRELESS NETWORK SYSTEM

This system consists of two subsystems: 1. Broadcast Unit connected with DM and AI Water Supply Management System 2. Substation Unit installed at different locations at water supply network asset including Pipeline Network at different spots, Valves at different locations, Water Resource Systems, Pressure Gauge systems, Leak Detection Monitoring Systems etc.

Both Broadcast Unit and Substation Unit establishes communication through big power data transmit Broadcasting Base Station as shown in the figure 3. The computer of Managing Center Real Time collects the data of each substation unit for the analysis of the system through exchanging data by net.

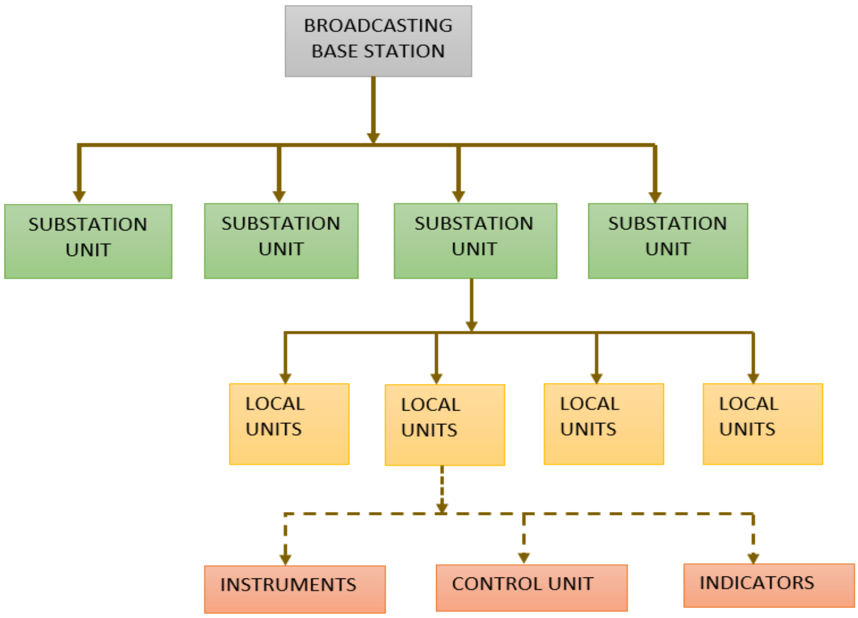

Figure 3: Broadcast and Wireless Network System block diagram

Wireless network infrastructure consists of gigabit optical fibers between local units and Substation units and provides adequate bandwidth and redundant data links in the backbone network. Client-Servers based network with switches and powerful processing capability Network Interface Cards. Network system is designed carefully to avoid network issues related to traffic and data security, optimized Virtual LAN (VLAN) is used to effectively isolate unnecessary broadcasting and unwanted data-stream [9].

Substation Unit is interconnected to Local Units**.** Local units collect data and controls the Instruments, and sends data to control units, indicators, and signals to controlling computers or handheld devices.

The Local Units are also called nodes within backbone network, use systematic code and sub-address code. Within every segment, a data concentration router manages each node. The data concentration router of lower level is the node of upper level. The way to encode the node address is to use its address code and the address code of the concentrator it belongs to.

Wireless communication protocol is established using Digital Audio Broadcasting which is based on the addressing communication using the communication methods known as “one to many “and “principal and subordinate”. Communication protocols like CAN and Ethernet are used in both wired and wireless are used for carrying data, status, and commands between different nodes.

III. APRIORI ALGORITHM

This algorithm is used in analysis of data in the Datawarehouse with huge number of transactions, this algorithm is also called frequent pattern mining. This is one of the Data Mining algorithms works based on association rule between objects to determine how two or more objects are related to one another and use the result of analysis to plan efficiently for optimized implementation and execution [10].

Apriori algorithm works on three components: Support, Confidence and Lift. Support refers to the default popularity, Confidence refers to the probability, and Lift refers to the increase in ratio of transaction. In this water supply data transaction details for five areas from Monday to Saturday i.e., D = {Mon, Tue, Wed, Thu, Fri, Sat}, has been analyzed to efficiently calculate the common valve position based on association rule to different areas, A = {A1, A2, A3, A4, A5}. The table below gives the water supply transaction details for six days represented as rows and five areas represented as columns.

Sl.NO	Day	Area covered
1	Mon	A1A2A3
2	Tue	A2A3A4
3	Wed	A4A5
4	Thu	A1A2A4
5	Fri	A1A2A3A5
6	Sat	A1A2A3A4A5

Table1: Area set for water supply.

In this case we are using minimum support i.e.,
min_sup = 3 and minimum confidence = min_sup/No of Transaction Days = 3/6*100 = 50%
Step1: K = 1
Create a table of support count for each area present in dataset called Area set C1.

Sl.NO	Areaset	sup_count
1	A1	4
2	A2	5
3	A3	4
4	A4	4
5	A5	3

Table2: Area set C1.

Compare C1 support count with minimum support count (min_sup = 3) if support count of C1 areas less than 3 then remove those areas. In the above table support count of all areas are above minimum support so new table L1 is same as C1.

Generate Support Values for A1, A2, A3, A4, A5 from Area set C1:
Support value is the ratio of number of transactions particular area appears to the total number of transactions.

- Support(A1) = Number of transactions in which the A1 appears/Total number of transactions = 4/6 = 0.66
- Support(A2) = 5/6 = 0.83, Support(A3) = 4/6 = 0.66, Support(A4) = 4/6 = 0.66, Support(A5) = 3/6 = 0.5

Step2: K = 2
Generate area set C2 joining L1. Condition of joining L_{k-1} and L_{k-1} is that it should have K-2 elements in common.
Check all subsets of an area set are frequent or not if not remove that area set.

Sl.NO	Areaset	sup_count
1	A1A2	4
2	A1A3	3
3	A1A4	2
4	A1A5	2
5	A2A3	4
6	A2A4	3
7	A2A5	2
8	A3A4	2
9	A3A5	2
10	A4A5	2

Table3: Area set C2.

Compare C2 support count with minimum support count (min_sup = 3) if support count of C2 areas less than 3 then remove those areas and generate L2 Area set by removing area with minimum support less than 3.

Sl.NO	Areaset	sup_count
1	A1A2	4
2	A1A3	3
3	A2A3	4
4	A2A4	3

Table4: Area set L2.

Generate Support values for Area set L2:

- Support(A1A2) = Number of A1A2 Transactions/Total Number of Transactions = 4/6 = 0.66
- Support(A1A3) = 3/6 = 0.5, Support(A2A3) = 4/6 = 0.66, Support(A2A4) = 3/6 = 0.5

Step 3: K = 3
Generate area set C3 joining L2.

Sl.NO	Areaset	sup_count
1	A1A2A3	3
2	A2A3A4	2

Table5: Area set C3.

Compare C3 support count with minimum support count (min_sup = 3) if support count of C3 areas less than 3 then remove those areas and generate L3 Area set by removing area with minimum support less than 3. Here, remove A2A3A4 from C3.

Sl.NO	Areaset	sup_count
1	A1A2A3	3

Table6: Area set L3.

Generate Support values for Area set L3:

- Support(A1A2A3) = 3/6 = 0.5

At step 3 no frequent area sets are found further.

We have generated now frequent area sets from step 1 to 3 and generated corresponding Support values. Next step is to generate Confidence value for the strong association rule A1A2A3 generated in L3 based on minimum support value.

Confidence and Lift calculation for each rule:
Take frequent area set and calculate confidence and Lift for each rule for the area set A1A2A3 from L3.

- [A1^A2] =>[A3]:

Confidence(A1A2) = sup(A1A2A3)/sup(A1A2) = 3/4*100 = 75%
Signifies 75% of the times when A1 and A2 areas are supplied water, A3 area is also supplied.

Lift(A1A2=>A3) = sup(A1A2A3)/[sup(A1A2) ×sup(A3)] = 1.262
Signifies positive correlation as value is >1 and when A3 is supplied water, A1 and A2 are also supplied.

- [A1^A3] =>[A2]:

Confidence(A1A3) = sup(A1A2A3)/sup(A1A3) = 3/3*100 = 100%
Signifies 100% of the times when A1 and A3 areas are supplied water, A2 area is also supplied.

Lift(A1A3=>A2) = sup(A1A2A3)/[sup(A1A3) ×sup(A2)] = 1.204
Signifies positive correlation as value is >1 and when A2 is supplied water, A1 and A3 are also supplied.

- [A2^A3] =>[A1]:

Confidence(A2A3) = sup(A1A2A3)/sup(A2A3) = 3/4*100 = 75%
Signifies 75% of the times when A2 and A3 areas are supplied water, A1 area is also supplied.

Lift(A2A3=>A1) = sup(A1A2A3)/[sup(A2A3) ×sup(A1)] = 1.262
Signifies positive correlation as value is >1 and when A1 is supplied water, A2 and A3 are also supplied.

- [A1] =>[A2^A3]:

Confidence(A1) = sup(A1A2A3)/sup(A1) = 3/4*100 = 75%
Signifies 75% of the times when A1 area is supplied water, A2 and A3 areas are also supplied.

Lift(A1=>A2A3) = sup(A1A2A3)/[sup(A2A3) ×sup(A1)] = 1.262
Signifies positive correlation as value is >1 and when A2 and A3 are supplied water, A1 also supplied.

- [A2] =>[A1^A3]:

Confidence(A2) = sup(A1A2A3)/sup(A2) = 3/5*100 = 60%
Signifies 60% of the times when A2 area is supplied water, A1 and A3 areas are also supplied.

Lift(A2=>A1A3) = sup(A1A2A3)/[sup(A1A3) ×sup(A2)] = 1.204
Signifies positive correlation as value is >1 and when A1 and A3 are supplied water, A2 also supplied.

- [A3] =>[A1^A2]:

Confidence(A3) = sup(A1A2A3)/sup(A3) = 3/4*100 = 75%
Signifies 75% of the times when A3 area is supplied water, A1 and A2 areas are also supplied.

Lift(A3=>A1A2) = sup(A1A2A3)/[sup(A1A2) ×sup(A3)] = 1.262
Signifies positive correlation as value is >1 and when A1 and A2 are supplied water, A3 also supplied.

Confidence values for all the above rules are meeting minimum confidence 50% and Lift values for all association rules are greater than 1. So, all 6 rules can be considered as strong association rules.
The graph of L1 and L2 Area set is shown in the below figure 4 based on the generated Support value and Confidence value in the table 7 and table 8.

Association Rule L2	Confidence Value	Support Value
A1A2	0.75	0.66
A1A3	1.00	0.50
A2A3	0.75	0.66

Table 7: Association Rule Values for L2

Association Rule L1	Confidence Value	Support Value
A1	0.75	0.66
A2	0.60	0.83
A3	0.75	0.66

Table 8: Association Rule Values for L1

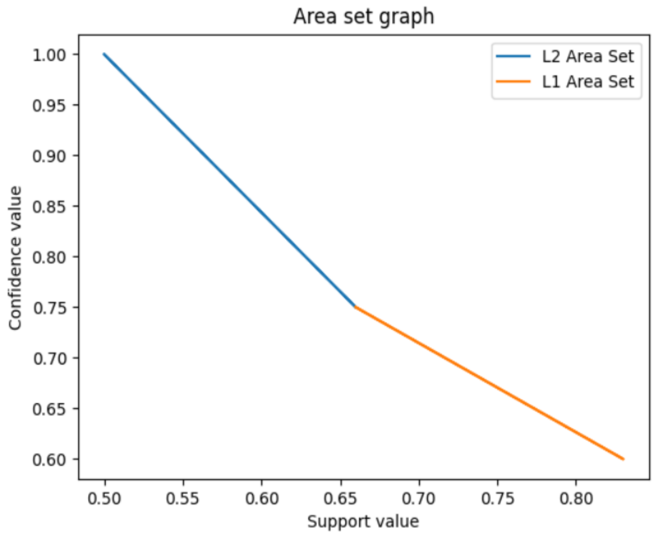

Figure 4: Area set graph.

Figure 4 gives analogy that individual area set L1 Confidence value ranges from 0.60 to 0.75 but using strong Association rule from area set L2 Confidence value extended from 0.75 to 1.0 that is the advantage of strong association.

Based on these rules discovered from the Data Mining system using Apriori algorithm the Valve positions are operated which are distributed across different areas from A1 to A6 efficiently for the corresponding days from Monday to Saturday. In this way Data Mining algorithms like Apriori, Support Vector Machine, Naïve Bayes Algorithms can be applied to solve complex problems in Civil Engineering, Environmental Engineering, Real Time Embedded and Automated Engineering use cases to optimize the services.

IV. CONCLUSION

The Data Driven approach using Data Mining and Artificial Intelligence technology in dynamically changing and complicated Water Supply Management Systems increases the performance and integrity of the system without compromising in cost index and reducing human efforts and errors. Use of Electronic Control Units helps to receive data from the sensors and GIS system for the different parameters like water resources status like quantity and quality, pipeline network conditions and status, valve condition and position, leakage detection in pipes and valves, time co-ordinates, location co-ordinate and geographical co-ordinates.

The use of Date Warehouse and Data Mining systems as Central Management system helps in organizing and processing the data from different water supply network assets using ECUs and Data Concentrator Integrator Systems. Use of algorithms like Apriori in determining the minimum confidence between objects and it's use in making decision to adjust valve position across strong association areas simultaneously.

AI system imports data from DM and builds the data model to generate commands, data and status using Artificial Neural Network Algorithms. AI model control the remote nodes using wireless communication network through Control and Dispatch Systems and high-power Broadcast Unit. Broadcasting Base station receives data from the centralized management system and sends it to Substation units. Local units receive data from the substation units and sends it to Instruments, control units, indicators, and handheld devices.

V. ACKNOWLEDGEMENT

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