Modeling a hierarchical structure of factors influencing exploitation policy for water distribution systems using ISM approach

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Abstract. Water distribution systems are one of the basic elements of contemporary technical infrastructure of urban and rural areas. It is a complex engineering system composed of transmission networks and auxiliary equipment (e.g. controllers, checkouts etc.), scattered territorially over a large area. From the water distribution system operation point of view, its basic features are: functional variability, resulting from the need to adjust the system to temporary fluctuations in demand for water and territorial dispersion. The main research questions are: What external factors should be taken into account when developing an effective water distribution policy? Does the size and nature of the water distribution system significantly affect the exploitation policy implemented? These questions have shaped the objectives of research and the method of research implementation.

1. Introduction
Water distribution systems are one of the basic elements of contemporary technical infrastructure of urban and rural areas. It is a complex engineering system composed of transmission networks and auxiliary equipment (e.g. controllers, checkouts etc.), scattered territorially over a large area. From the water distribution system operation point of view, its basic features are: functional variability, resulting from the need to adjust the system to temporary fluctuations in demand for water and territorial dispersion, which on the one hand allows for the realization of the basic goal of supplying water to consumers; while on the other is a serious impediment to maintenance work (inspections, repairs, etc.) as it implies the need to move people and equipment necessary to carry out the work and to ensure proper communication. In the exploitation policy of the water distribution network, especially in the case of temporary fluctuations in the demand for water, even advanced IT techniques such as artificial intelligence, including neural networks, should be used. In Poland, research is being carried out on forecasting of the water distribution network load over different periods of time [1,2]. Environmental aspects are also important during the development (design) and operation of the water distribution network. The literature [3,4] can be used here.
It is important to note that water distribution networks are usually large assets, of the value significantly higher than the income of its operator. There is therefore no financial or technical capacity to reproduce a significant part of the network in a short period of time. Hence, it is important to adopt exploitation policy so that, by systematic actions of a small extent (compared to the size and value of the facility being used), not only maintain the whole system and keep it exploitation, but continuously adjust it to growing requirements (increasing number of customers, increase in the length of the water distribution network, changes in legal requirements, etc.).

The main research questions are: What external factors should be taken into account when developing an effective water distribution policy? Does the size and nature of the water distribution system significantly affect the exploitation policy implemented? These questions have shaped the objectives of research and the method of research implementation. The objectives of the research are: (1) To identify and rank the external factors (variables) influencing the exploitation policy of the water distribution network; (2) To establish the relationship among these identified variables (3) To develop a structural model using Interpretive Structural Modeling (ISM); (4) To carry out MICMAC analysis. The research included the exploitation policy of the small water distribution network in less urbanized areas and compared the importance of the criteria considered for this network and the typical urban network described by [5, 6].

The article is composed of five chapters. Chapter 2 describes the ISM methodology, defines the objective of the method, its implementation, and literature review of the ISM method. The next chapter is the research part. This chapter includes characteristics the research object and analysis of the factors influencing the exploitation policy of the presented water distribution network. The simplified scheme is illustrated in Figure 1.

![Figure 1. Simplified scheme of the procedure](image)

In the Chapter 4, the MICMAC (Matrice d'Impacts cossovers-multiplication appliquée anclassment) analysis was conducted, which allowed for an assessment of the influence and dependence of the variables and the visualization of the results. A comparative analysis of the results obtained for a large water distribution network supporting urban agglomerations was also conducted with the results obtained for the water distribution network serving the small municipality. The last chapter is a summary and identification of directions for further research.

2. Interpretive Structural Modeling - ISM

In the literature, three main techniques like: Interpretive Structural Modeling, Analytic Network Process and Analytic Hierarchy Process are used for modeling and multi criteria decision making (MCDM) in the different area [7, 8, 9]. Jitesh Thakkar et al. [10] have compared these three techniques and extracts from that comparison is shown in the Table 1. This comparison aims to represent the main advantages of ISM technique.
Table 1. Brief comparison between AHP, ANP and ISM [10]

| Analytic Hierarchy process (AHP) | Analytic Network Process (ANP) | Interpretive Structural modeling Technique (ISM) |
|---------------------------------|-------------------------------|-----------------------------------------------|
| Discipline of hierarchy to be strictly followed | Deals with loose networks | Involves a set of Interconnected criteria |
| Fails in complex real life problems | Useful in real life non-linear problems | Captures the complexities of real life problems |
| Assumes functional independence of an upper part of hierarchy from its lower one | Takes into account the Interdependencies and non-linearity | Establishes the “leads to” relationships among the criteria |
| Moderate ability for capturing dynamic complexity | Lower ability for capturing complexity | Higher ability for capturing dynamic complexity |

Interpretive Structural Modeling was first proposed by J. Warfield [11] to analyze the complex socioeconomic systems. ISM is a computer-assisted learning process that enables individuals or groups to develop a map of the complex relationships between the many elements involved in a complex situation. Its basic idea is to use experts’ practical experience and knowledge to decompose a complicated system into several sub-systems (elements) and construct a multilevel structural model.

Warfield developed a methodology that uses systematic application of some elementary notions of graph theory and Boolean algebra in such a way that when implemented in a man machine interactive mode, theoretical, conceptual and computational leverage is exploited to construct directed graph (a representation of the hierarchical structure of the system). This methodology has at least two desirable properties when compared to the similar approaches namely simplicity in the sense of not requiring from the user i.e. viewpoint of advance mathematical knowledge and efficiency in terms of economizing in computer time.

The various steps involved in ISM modeling are as follows: (1) Identify the elements which are relevant to the problem. This could be done by a survey or group problem solving technique; (2) Establish a contextual relationship between elements with respect to which pairs of elements would be examined; (3) Develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pair-wise relationship among elements of the system. This matrix is checked for transitivity; (4) Develop a reachability matrix from the SSIM; (5) Partition the reachability matrix into different levels; (6) Convert the reachability matrix into conical form; (7) Draw digraph based on the relationship given in reachability matrix and remove transitive links and convert the resultant digraph into an ISM based model by replacing element nodes with the statements; (8) Review the model to check for conceptual inconsistency and make the necessary modifications.

ISM is an interactive learning process. In this technique, a set of different directly and indirectly related elements are structured into a comprehensive systematic model. Applications of ISM in various systems/fields is shown in the Table 2.

Table 2. Applications of ISM in various systems/fields

| Reference | System/field |
|-----------|--------------|
| Amrina et al., 2016 [12] | This paper aims to propose a fuzzy multi criteria approach for evaluating sustainable manufacturing in cement industry which integrated the Interpretive Structural Modeling (ISM) and the Fuzzy Analytic Network Process (FANP) methodology. |
| Kumar et. Al., 2013 [13] | The study developed a structural model of the variables, important to implement Lean Manufacturing System in Indian automobile industry. The model based upon experts’ opinions. Eighteen variables have been identified from the literature and subsequent discussions with experts. |
| Panackal & Singh (2015) [14] | The study reflected various fields of contribution of rural youth towards sustainable development and significant important areas for improvement High interrelationship and interconnectivity between the rural youth and sustainability was derived from ISM Model. |
3. Methodology

3.1. Introduction of the object of the research

The object of the research is a water distribution network supplying the Śmigiel municipality. The first plans for construction of the Śmigielski aqueduct were made in 1911. Currently the water distribution network extends over a total area of 185.5 km², of which 134.3 km² is the rural area and 51.2 km² is urban area. The water distribution network consists of 6 water intake stations, and the total daily water production is 2146 m³ and supplies about 18 thousand residents. Table 3 summarizes the length of the water distribution network of Śmigiel municipality in the years 2012 - 2016, while table 4 shows the age structure of the water distribution system elements.

Table 3. The length of the water distribution network in Śmigiel municipality in the years 2012-2016

| YEAR | Length of the network [km] |
|-------|-----------------------------|
|       | 2012 | 2013 | 2014 | 2015 | 2016 |
| Type of the network | distribution | 187.7 | 187.7 | 189.2 | 189.2 | 189.2 |

Table 4. Age structure of the water distribution network in Śmigiel municipality

| Age of the ducts | Up to 5 years | between 6-10 years | between 11-20 years | over 20 years |
|------------------|---------------|---------------------|---------------------|---------------|
| Percentage       | 5%            | 15%                 | 20%                 | 60%           |

The network includes mainly pipes made of: cement-asbestos, PVC, cast iron and steel. The percentage of materials from which the water distribution network is made of is shown in Table 5.

Table 5. Percentage of materials from which the water distribution network is made of in Śmigiel municipality

| Material     | PCV | Steel | Cast iron | PE | Cement-asbestos |
|--------------|-----|-------|-----------|----|-----------------|
| Percentage   | 65% | 0%    | 15%       | 2% | 18%             |

The goal of the enterprise is to supply water to the consumers, providing: (1) quantitative parameters, taking into account needs of customers varying in time and space (2) quality parameters, taking into account the need to adjust and maintain the water characteristics at the level defined by
legal requirements. In pursuit of such goals, the network's performance is crucial for the company, including:

- operation aspect - providing organizational and economic conditions for the efficient use of all network elements (sale of water produced to end users)
- maintenance aspect - providing technical capabilities for effective operation and efficient use of the network, by monitoring and maintaining parameters at the required level, e.g. water pressure in the network, carrying out scheduled inspections, maintenance and repairs and performing unscheduled work resulting from emergency events.

It is important for network managers to consider what external factors should be taken into account when determining the exploitation policy for water distribution network, and which of them will have the greatest impact both on the performance of the customer response and on the company's own efficiency

3.2. Identification of external factors influencing exploitation policy of Śmigiel water distribution system

The research was to identify, select and organize a set of features describing the impact of the external environment on the water distribution network's exploitation policy. Due to the objective of the research, the external environment features developed by A. Loska [5] for the large water distribution system were used for further consideration. The identification of the external environment was carried out in the research with an expert method (involving researchers and employees of the company) using the STEEPVL model. This model includes seven criterion classes, each of which determines the selected aspect of the external environment: Social, Technological, Economic, Ecological, Political, Value, Legal. The identified features for each of the criteria classes are shown in the Table 6.

**Table 6.** The list of the factors, as a result of the analysis using the STEEPVL model [5].

| Criteria         | Features (F)                                                                 |
|------------------|-----------------------------------------------------------------------------|
| Social           | (1) Level of request and consumption of water in the activity area of the enterprise. |
|                  | (2) Staff potential of the enterprise.                                     |
|                  | (3) Staff potential of the maintenance department of the enterprise        |
| Technological    | (4) Access to innovative exploitation solutions on the water supply system. |
|                  | Level of modernity of the water supply system.                            |
|                  | (5) Access to innovative exploitation solutions on the water supply system.|
|                  | (6) Level of the use of innovative methods and tools in the exploitation of the water supply system. |
| Economic         | (7) Dynamics of changes in the price (cost) of water supply to consumers.  |
|                  | (8) Expenditures for development and modernization of the water supply system.|
|                  | (9) Expenditures for activities of the maintenance department.             |
| Ecological       | (10) Influence of the water supply system on the environment.              |
|                  | (11) Impact of exploitation activities for the water supply system on the environment. |
| Political        | (12) State and region policy in the field of water management.            |
|                  | (13) Enterprise policy for ensuring supply of water to customers.          |
|                  | (14) Importance of the maintenance activity for the enterprise.           |
| Value            | (15) Life style and consumption patterns of the local community.          |
|                  | (16) Level of acceptance of maintenance works of the water supply system by the local community. |
| Legal            | (17) Legislation in the supply of water to consumers.                     |
|                  | (18) Legal requirements and standards for the exploitation of the water supply system. |
The criteria and features presented in Table 6 were further investigated by a panel of experts.

3.3. Interpretive Structural Modeling approach

Analysis of external factors influencing the definition of exploitation policy of the water distribution network in Śmigiel municipality was carried out with respect to the stages presented in figure 2. These stages were divided into five steps.

Step 1 Structural self-interaction matrix (SSIM)

For developing contextual relationships among variables, the opinion of total five experts, three from industry and two from academia have been taken. For expressing the relationship between different critical factors, four symbols have been used to denote the direction of relationship between the parameters i and j (here i, j): V is used for the relation from enabler i to enabler j (i.e. if enabler i influences or reaches to enabler j); A is used for the relation from enabler j to enabler i (i.e. if enabler j reaches to enabler i); X is used for both direction relations (i.e. if enablers i and j reach to each other); O is used for no relation between two enablers (i.e. if enablers i and j are unrelated). Based on this contextual relationship, the SSIM has been developed. To obtain consensus, the SSIM was discussed in a group of factory experts and based on their responses, SSIM has been finalized and is presented in Table 7.

Table 7. Structural self-interaction matrix (SSIM)

| F_i | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|
| 1   | V | V | 0 | 0 | V | V | 0 | 0 | 0 | X | V | V | A | V | 0 | V |
| 2   | X | 0 | 0 | A | A | X | 0 | 0 | 0 | 0 | A | A | 0 | 0 | 0 | 0 |
| 3   | 0 | 0 | X | 0 | 0 | V | 0 | 0 | 0 | A | X | 0 | X | 0 | 0 |
| 4   | A | A | 0 | X | 0 | V | 0 | 0 | A | V | 0 | V | 0 | 0 |
| 5   | V | 0 | 0 | A | 0 | 0 | 0 | V | A | 0 | 0 | 0 | V |
| 6   | V | X | X | 0 | X | 0 | 0 | A | 0 | X | 0 | A |
| 7   | A | A | A | A | A | A | 0 | X | V | A | 0 |
| 8   | V | X | V | A | X | X | 0 | 0 | A | A |
| 9   | V | X | 0 | A | X | 0 | A | 0 | A |
| 10  | V | 0 | 0 | 0 | 0 | 0 | A | 0 |
| 11  | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 12  | V | 0 | 0 | 0 | V | 0 |
| 13  | V | A | 0 | 0 | A |
| 14  | 0 | X | 0 | A |
| 15  | V | A | 0 |
| 16  | 0 | 0 |
| 17  | 0 | 0 |

Step 2 Reachability matrix

The SSIM is transformed into a reachability matrix format by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix. The substitution of 1s and 0s are as per the following rules: (1) If the (i, j) entry in the SSIM is V, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0; (2) If the (i, j) entry in the SSIM is A, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1; (3) If the (i, j) entry in the SSIM is X, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1; (4) If the (i, j) entry in the SSIM is O, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0. Following the above rules, the initial reachability matrix is prepared and is shown in tab.8.
Table 8. Initial reachability matrix

| $F_i$ | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     | 0  | 1  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 0  | 1  |
| 2     | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 3     | 0  | 1  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 1  | 0  | 0  |
| 4     | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 0  |
| 5     | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  |
| 6     | 0  | 1  | 0  | 0  | 1  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  |
| 7     | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 0  |
| 8     | 0  | 1  | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 9     | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 10    | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 11    | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  |
| 12    | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 13    | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  |
| 14    | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |
| 15    | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  |
| 16    | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  |
| 17    | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 18    | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |

* entries are included to incorporate transitivity to fill the gap, if any, in the opinion collected during development of structural self-instructional matrix. After incorporating the transitivity concept as described above, the final reachability matrix is obtained (table 9).

Table 9. Final reachability matrix

| $F_i$ | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     | 1  | 1  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 2     | 0  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 3     | 0  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 4     | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 5     | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 6     | 0  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 7     | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 8     | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 9     | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 10    | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 11    | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 12    | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 13    | 0  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 14    | 0  | 1  | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 15    | 1  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 16    | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 17    | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |
| 18    | 0  | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* | i* |

Step 3 Partitioning the reachability matrix

The matrix is partitioned, by assessing the reachability and antecedent sets for each variable. The reachability set consists of the element itself and other elements, which it may help to achieve,
whereas the antecedent set consists of the element itself and other elements, which may help achieving it. Thereafter the intersection of these sets is derived for all the elements. The elements for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. The top-level element in the hierarchy would not help achieve any other element above its own level. Once the top-level element is identified, it is separated out from the other elements. Then, the same process is repeated to find out the elements in the next level. This process is continued until the level of each element is found. These levels help in building the digraph and the ISM model. In the present case, the 18 enablers, along with their reachability set, antecedent set, intersection set and levels, are presented in table 10.

| Fj | Reachability set R(pj) | Antecedent set A(pj) | Intersection set R(pj) ∩ A(pj) | Level |
|----|------------------------|----------------------|--------------------------------|-------|
| 1  | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,7,12,15 | 1,7,12,15 | X |
| 2  | 2,3,4,6,7,8,9,10,11,13,14,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,6,7,8,9,10,11,13,14,16 | III |
| 3  | 2,3,4,5,6,7,8,9,10,11,14,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,13,14,16 | IV |
| 4  | 2,3,4,5,6,7,8,9,10,11,12,13,14,16 | 1,2,3,4,5,6,8,9,10,11,12,13,14,16,17,18 | 2,3,4,5,6,7,8,9,10,11,12,13,14,16 | V |
| 5  | 2,3,4,5,6,7,8,9,10,11,13,14,16,18 | 1,3,4,5,9,11,14,16 | 3,4,5,9,11,14,16 | IX |
| 6  | 2,3,4,6,7,8,9,10,11,13,14,15,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,6,7,8,9,10,11,13,14,15,16 | IV |
| 7  | 1,2,3,4,6,7,8,9,13,14,15,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,6,7,8,9,13,14,15,16 | II |
| 8  | 2,3,4,6,7,8,9,10,11,13,14,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,6,7,8,9,10,11,13,14,16 | III |
| 9  | 2,3,4,5,6,7,8,9,10,11,13,14,16,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18 | V |
| 10 | 2,4,6,7,8,9,10,11,13,14,15,16 | 1,2,3,4,5,6,8,9,10,11,12,14,15,16,17,18 | 2,4,6,8,9,10,11,14,16 | III |
| 11 | 2,3,4,5,6,7,8,9,10,11,14,15,16 | 1,2,3,4,5,6,8,9,10,11,12,14,15,16,17,18 | 2,3,4,5,6,8,9,10,11,14,16 | VI |
| 12 | 1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,4,12,15 | 1,4,12,15 | X |
| 13 | 2,3,4,6,7,8,9,10,13,14,16 | 1,2,4,5,6,7,8,9,10,12,13,14,15,17,18 | 2,4,6,7,8,9,13,14 | I |
| 14 | 2,3,4,5,6,7,8,9,10,11,13,14,16,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,13,14,16,18 | V |
| 15 | 1,2,3,4,6,7,8,9,12,13,14,15,16,18 | 1,6,7,9,10,11,12,15,17,18,19 | 1,6,7,9,12,15,18 | VI |
| 16 | 2,3,4,5,6,7,8,9,10,11,14,16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,13,14,16,18 | IV |
| 17 | 2,7,8,9,10,11,13,14,15,16,17 | 1,12,17 | 17 | VI |
| 18 | 2,3,4,6,7,8,9,10,11,13,14,15,16,18 | 1,5,9,12,14,15,18 | 9,14,18 | VI |

**Step 4 Development of conical matrix**

Conical matrix is developed by clustering factors in the same level across the rows and columns of the final reachability matrix. The drive power (DRP) of a factor is derived by summing up the number of ones in the rows and its dependence power (DEP) by summing up the number of ones in
the columns. Next, drive power and dependence power ranks are calculated by giving highest ranks to the factors that have the maximum number of ones in the rows and columns, respectively (Table 11).

**Table 11. Conical matrix**

| F_i | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | DRP |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|
| 1   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 18 |
| 2   | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 12 |
| 3   | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| 4   | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 5   | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 6   | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| 7   | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| 8   | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| 9   | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| 10  | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 15 |
| 11  | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| 12  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 17 |
| 13  | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 14  | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 15  | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 13 |
| 16  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| 17  | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 11 |
| 18  | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 14 |
| **DEP** | **4** | **18** | **16** | **15** | **8** | **17** | **18** | **18** | **15** | **15** | **4** | **15** | **18** | **9** | **18** | **3** | **7** |

### Step 5 Development of digraph and ISM model

From the conical form of reachability matrix, the preliminary digraph including transitive links is obtained. It is generated by nodes and lines of edges. After removing the indirect links, a final digraph is developed. In this development, the top level factor is positioned at the top of the digraph and second level factor is placed at second position and so on, until the bottom level is placed at the lowest position in the digraph.

### 4. MICMAC analysis

Matrice d’Impacts croises-multiplication appliquée anclassment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The purpose of MICMAC analysis is to analyze the drive power and dependence power of enablers. MICMAC principle is based on multiplication properties of matrices. It is done to identify the key enablers that drive the system in various categories. Based on their drive power and dependence power, the enablers, have been classified into four categories as follows: (1) Autonomous enablers: These enablers have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong; (2) Linkage enablers: These enablers have strong drive power as well as strong dependence power. They enablers are unstable in the fact that any action on these enablers will have a effect on others and also a feedback effect on themselves; (3) Dependent enablers: These enablers have weak drive power but strong dependence power (4) Independent enablers: These enablers have strong drive power but weak dependence power. An enabler with a very strong drive power, called the ‘key enabler’ falls into the category of independent or linkage enablers. The drive power and dependence power of enablers is shown in table 11. The drive power - dependence power diagram is drawn as shown in Fig. 2 This Figure has been divided into four clusters. First cluster includes ‘autonomous enablers’, second cluster includes ‘dependent enablers’, third cluster includes ‘linkage enablers’ and fourth cluster contains ‘independent enablers’.

There are for example (17) Legislation in the supply of water to consumers; (15) Life style and consumption patterns of the local community factors in the autonomous cluster. The next cluster
consists of dependent variables like: (10) Influence of the water supply system on the environment, (3) Staff potential of the maintenance department of the enterprise, (11) Impact of exploitation activities for the water supply system on the environment. In this particular cluster, these variables have the least driving power and have highest dependence and form the topmost level in the ISM hierarchy. The managers should take special care for handling these enablers. The next cluster consists of those variables that are termed as linkage variables like (9) Expenditures for activities of the maintenance department and (4) Access to innovative exploitation solutions on the water supply system Level of modernity of the water supply system, which are influenced by lower level variables and in turn impacts other variables in the ISM model. The last cluster includes independent variables like (1) Level of request and consumption of water in the activity area of the enterprise and (12) State and region policy in the field of water management. These variables have strong driving power and weak dependency on other enablers. They may be treated as the ‘key enablers’ for the successful implementation of exploitation policy for water distribution network.

![Figure 2. MICMAC Direct influence/dependence map (Smigiel)](image)

To answer the question: Does the size and nature of the water distribution system significantly affect the adopted exploitation policy? It is necessary to compare the research results for the large metropolitan water distribution system (MS) with the results obtained in the research presented in the paper. Because the method described by J. Nazarko [18] was used in the research (MS), the results were to be transposed into the ISM matrix so that the data prepared could be used to develop the MICMAG graph. Graphs of water distribution networks compared are shown in the Figure 3.
The comparison showed that depending on the size of the water distribution system, different criteria are of various importance for the water distribution network exploitation policy definition. There is considerable variation in the approach to maintenance and repair (14), network development and modernization (8) and the use of innovative solutions (6). In a large enterprise, these factors are considered as the crucial ones - large enterprises have the resources and capabilities to innovate and plan for the long-term exploitation of the network, shaping its future prospects. On the one hand, it seems advisable to pursue further action striving for identifying the impact of individual factors on corporate policy and identifying undisclosed factors, on the other hand it signals the need for search for the reasons why innovation is less important as innovation - Is it just a result of smaller financial resources, or are there other causes? Criteria that in both cases are of comparable importance, are, among others (1) (9) and (17) - companies are striving to achieve their primary goal, i.e., water distribution (probably) minimizing maintenance expenditure, paying attention to legal regulations in this regard but treating them as external factor, which they have no influence on.

5. Conclusion

The major objective of this paper is to identify the factors that significantly affect the exploitation policy for water distribution system. In this paper, an ISM-based model has been developed to analyze the interactions among different external factors influencing water distribution system in a small municipality.

The ISM model developed in this paper acts as a tool for top management to understand/identify the key enablers of external factors influencing exploitation policy for water distribution system in a small municipality. This model has been developed on the basis of consensus of experts from industry and authors of this paper. Comparison between two water distribution network (small and large metropolitan water distribution system) indicate that 3 factors are of comparable importance, are, among others (1) (9) and (17) - companies are striving to achieve their primary goal, i.e., water distribution (probably) minimizing maintenance expenditure, paying attention to legal regulations in this regard but treating them as external factor, which they have no influence on.
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