Cybernetic approach in urban water management

Approche cybernétique en hydrologie urbaine

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RESUME

Pour analyser la complexité du réseau d'assainissement de l'Agence de l'Eau de Pinneberg (AZV), une approche cybernétique selon Vester (1990a) a été utilisée. L'objectif de cette approche est l'intensification de la compréhension du système avec toute sa diversité, en évitant des simplifications qui barrent la vue vers des effets cachés. L'approche choisie permettait une meilleure compréhension de la complexité du système, introduisait un « language » commun parmi les membres du groupe et réduisait le nombre de malentendus et mauvaise interprétations. Maintenant, les membres du groupe font la différence entre les variables du réseau d'assainissement actives et passives, ainsi que sensibles et stockantes. Finalement, cette compréhension de la cybernétique du système a permis aux acteurs du AZV de reconnaître quelles boucles de contrôle serait susceptibles d'initier des changements.

ABSTRACT

A cybernetic approach introduced by Vester (1990a) was used to investigate the complexity of the urban water system of the cooperative sewage association Pinneberg (AZV). The aim of the approach is to intensify the understanding about the system with its diversity, without simplifying it in a way, that hidden effects are disregarded and by this overseen. The approach caused a better understanding of the systems complexity, forced a common "language" among the members of the team and reduced the number of misinterpretation. The team members distinguish the active and passive as well as the sensitive and buffering variables in the urban water system now. Finally the understanding of the cybernetic of the system lead the AZV-members to the awareness which control loops might be suitable to initiate changes.

KEYWORDS

Complexity of interactions, cybernetic approach, urban water management.

1 INTRODUCTION

Urban water systems are characterized by very complex ecological, economical and social interactions. The improvement of urban water systems by changing only few influencing variables will fail, except development takes place very slow. A more efficient and quick way to find a highly developed and stable urban water system needs an integrated urban water management strategy.

Besides strategies basing on fuzzy logic or complex optimization the cybernetic approach introduced by Vester (1990a, 1990b, 2004) fulfils the necessary requirements. In this case study parts of the cybernetic approach, introduced by Vester were used to consider the complexity of interactions in the urban water system of the cooperative sewage association Pinneberg (AZV) in Schleswig-Holstein, Germany. The case study is mainly focusing on the cybernetic approach and its practicability in engineering practice.

In a second stage of the cybernetic approach subsystems, indicated during the first stage, will be investigated. Results of both stages shall later be introduced to the management concept of the AZV. The overall aim is to stabilize the system against disorder and to minimize resource inputs.

2 URBAN WATER SYSTEM OF THE COOPERATIVE SEWAGE ASSOCIATION PINNEBERG (AZV)

The cooperative sewage association Pinneberg (AZV) is managing the sewage of 38 communities (including parts of Hamburg City). She is operating a 160 km sewage system with 26 pumping stations. At these pumping stations or at measurement sites the waste water, which is drained by the communities (combined and separate systems) is entering the AZV-system. A final three stage treatment plant (700.000 IE) at the village Hetlingen is clarifying the waste water before discharging it into the river Elbe. Besides the river Elbe small creeks and rivers are used as receiving waters for the combined sewer overflows of the system. Some of the creeks are influenced by the tide of the North Sea as well as the river Elbe. Others are very sensitive due to their high grade of ecological standard. The main land use in the catchment is housing areas, light industry and intensive agricultural production of vegetables as well as tree nurseries. The slope of the catchment is in some sections very flat.

The main challenge of the system is described by its complexity with the following characteristics

- Different management strategies between the connected communities and the AZV
- Connection of combined and separate sewage systems with high amount of infiltration and storm water
- Sensitive rivers and creeks, partly with high ecological standard or with tide influence
- Very flat areas; the treatment plant is located in the flooding area of the Elbe
- Land use with high economical risks; rural and city subcatchments

A sustainable planning strategy needs a deep understanding of the interactions of the sewage system, sewage treatment plant and receiving waters. Since each subsystem is interrelated with different ecological, economical and social requirements the management board of AZV decided to carry out the cybernetic approach, introduced by Vester. Besides the team of Luebeck University and chosen members of the AZV some members from consulting companies took part in the approach. Members of the water authority were asked but had no time. Many different subjects of education were represented in the group, the number of men and women was nearly equal. Due to the limited time of all participating members a modified version of the cybernetic approach was carried out in the first stage.

3 METHODOLOGY OF THE CYBERNETIC APPROACH

The sensitivity model, developed by Vester is an approach to document the cybernetic of a system with its interactions, control loops and feedback. The aim of the model is to intensify the understanding about the system with its diversity. Further on, the model can be used to develop and check management strategies. In the final result a system shall be developed, which is stable against disorders, tolerant against mistakes and buffering impacts.

The way of working with the model is somehow completely different from engineering practice. In engineering practice interactions in the systems are often simplified as far as necessary, in order our technical solutions can solve the problem. With the sensitive model all interactions are taken into account for the description of the system, even side effects or strange impacts can be integrated in the model. By this procedure hidden effects can become of importance, if the cybernetic of the system assign them a dominant role. Less simple and less linear thinking guides the user to a sustainable planning tool.

The modified cybernetic approach is divided into six stages, which are not carried out in a linear way, but with several loops and feedback activities. Comparable to an iterative process of development the sensitivity model leads the user to strategic decisions for the concrete measures in the system. The six stages are worked out in a group of about 8 to 12 affected people and can be briefly described as follows

- <u>Definition of the system (1)</u> ⇔ Define the border of the system in space and time, in a way that the flow of material, energy and information across the border is minimal. Take social aspects and other non technical requirements of the society into account, which may influence the interactions in the system.
- <u>Identification of variables (2)</u> ⇔ During a brain storming all possible impacts, interactions and indicators of the system are collected by the members of the group. Out of these indicators key variables are identified and carefully defined. They have to be variable in deed, belong to the same level of the system and have to be “directed” (small ⇔ big, slow ⇔ fast etc.). They are somehow influencing the interactions in the whole system and by this they “play their role” in the system. Finally the definition is completed by sorting all indicators elected through the brain storming to the defined variables or chose an indicator as external impact which might disturb the system.

- Checking variables with respect to general system criteria (3) ⇔ In order to avoid a tendentious definition of variables, in the third stage the interactions between the variables and general system criteria are checked. By this stage the ability, completeness, proper balance and system relevance of the set of variables is proofed. In case of dissatisfaction a redefinition of the variables shall complete this stage.
- Matrix of variables (4) ⇔ In the fourth stage the impacts of each variable on every other variable is estimated. In this way even latent and small impacts and interactions are taken into account. The impacts between the variables are roughly estimated (0 = no impact, 1 = slight impact, 2 = medium impact, 3 = intense impact) and the result is drawn into the matrix of variables. Due to the rough estimation dissolution the results of most estimations are fuzzy, but step by step the picture of the system becomes sharp because of the large number of estimations done. Similarly, the role every variable plays in the system becomes clear more and more, even if the variable seems to be unimportant in the system.
- Role of each variable in the system (5) ⇔ The interpretation of the matrix of variables makes obvious, which variable plays an active or a passive and a buffering or a sensitive role in the system. Through this interpretation the attributes of the variables are identified. Some are critical, others can be used as effective lever for changing the system and finally some are perfect suitable for measuring the state of the system.
- Cybernetic of the system (6) ⇔ In stage 1 to 5 the “genetic fundamentals” were worked out. In the sixth stage it will be investigated how the “genetic fundamentals” affect the interactions of the system. Searching for complex pattern in the system is of more interest than linear if-than-roles. A network of control loops is developed in order to image the cybernetic of the system. A positive control loop may build up extreme situations in the loop. A negative control loop is buffering internal and external impacts and is able to adjust the system. Negative control loops should be dominant in the urban water system.

4 ANALYSIS OF THE “AZV URBAN WATER SYSTEM”

The definition of the system (1) and the identification of variables (2) were carried out for the “AZV urban water system” by the team of members from the AZV, university and consulting companies. These stages seem to be simple, but they are of outstanding importance for further communication, understanding the interactions in the system and to reduce misunderstanding. The more accurate these two stages were carried out, the more successful all further stages will be. The defined variables are listed in the matrix of variables.

During the checking of the variables with respect to the general system criteria (3) some light imbalances among the criteria “infrastructure” were identified. Two variables (Purification capacity of the treatment plant ⇔ resource consumption in the catchment area) were redefined to mitigate these effects. The development of the matrix of variables (4) is one the keys to successfully apply the sensitivity model by Vester. It is the first step of cybernetic description of the system. Each variable is listed on the x-axis and the y-axis in the same sequence and now the direct impact of one variable on every other variable is estimated in the following way and listed in the matrix of variables (**table 1**).

Table 1: matrix of variables		Evaluated impacts among system variables: 0: no or very slight impact; 1: slight impact or impact after a long time delay; 2: medium impact; 3: intense or very intense impact (bold: variables equally directed; underline: variables invers directed)																						
Effects of ⇩ on ⇨		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AS	PS	Q	P
State of river ecology	1		1	0	0	0	0	0	0	2	1	0	2	2	1	1	0	1	2	0	2	15	16	0,94	240
Intensity of river usage	2	3		0	0	0	0	0	0	1	0	0	2	2	2	2	0	0	2	2	2	18	22	0,82	396
Purification capacity of treatment plant	3	0	0		**3**	0	3	**3**	2	**3**	3	1	0	0	0	2	0	0	0	0	0	20	24	0,83	480
Amount of sewage sludge	4	0	0	2		0	0	**3**	2	0	**3**	0	0	0	1	2	0	0	0	1	1	15	23	0,65	345
Waste water production	5	1	1	3	**3**		3	**3**	2	0	3	0	0	0	0	2	0	0	0	1	1	23	18	1,28	414
Capacity of drainage system	6	2	3	2	2	0		**3**	2	**3**	2	0	0	1	0	0	0	0	2	1	1	24	26	0,92	624
Waste water charges	7	0	0	2	2	2	2		0	3	2	0	0	0	0	1	1	2	1	2	1	21	23	0,91	483
Efficiency of AZV-worker	8	1	0	**3**	3	0	2	1		1	3	2	0	0	0	1	1	2	0	0	0	20	22	0,91	440
Satisfaction of association members	9	0	0	0	0	0	0	3	1		2	0	1	0	0	0	0	2	0	0	2	11	21	0,52	231
Efficiency of AZV-management	10	0	0	**3**	3	0	**3**	3	**3**	2		**3**	1	0	0	0	1	1	0	0	1	24	32	0,75	768
Success of communication	11	0	0	2	2	0	**3**	0	2	0	3		1	0	0	1	1	1	0	1	2	19	14	1,36	266
Compulsion by laws and regulations	12	0	3	**3**	3	3	**3**	2	2	0	**3**	2		3	2	2	0	1	2	2	2	38	16	2,38	608
Intensity of catchment usage	13	3	2	0	0	**3**	2	0	0	0	0	0	1		2	**3**	0	0	3	**3**	2	24	22	1,09	528
Extent of mobility	14	2	2	0	0	2	0	0	0	0	0	0	0	2		**3**	0	1	**3**	2	2	19	21	0,90	399
Resource consumption in catchment area	15	1	1	1	0	2	1	1	0	0	1	0	1	1	1		1	1	2	**3**	1	19	31	0,61	589
Availability of information technology	16	0	1	**3**	2	0	**3**	0	2	2	2	**3**	0	1	2	1		**3**	**3**	**3**	2	33	11	3,00	363
Grade of education	17	2	2	0	0	2	0	0	1	1	1	1	1	2	2	2	1		**3**	2	3	26	20	1,30	520
Quality of life for citizens	18	1	2	0	0	2	0	0	1	1	1	0	2	2	**3**	**3**	1	0		2	2	23	28	0,82	644
Economic power	19	0	2	0	0	2	1	1	1	0	1	0	2	**3**	**3**	**3**	2	2	**3**		2	28	27	1,04	756
Efficiency of political activities	20	0	2	0	0	0	0	0	1	2	1	2	2	3	2	2	2	**3**	2	2		26	29	0,90	754
	PS	16	22	24	23	18	26	23	22	21	32	14	16	22	21	31	11	20	28	27	29				

AS: sum of active effects; PS: sum of passive effects

Quotient Q = AS / PS x 100; Product P = AS x PS

Table 1 : matrix of variables

The impacts among the system variables were evaluated as follows :

- 0 no or very slight impact
- 1 slight impact or impact after a long time delay
- 2 medium impact
- 3 intense or very intense impact

In order to develop the network of control loops in stage six, the direction of the intense and very intense impacts (evaluation with “3”) was investigated. In case of equally direction the “3” was drawn bold (i.e. increasing the amount of sewage sludge [4] leads to an increase of the waste water charges [7]), in case of inverse direction the “3” was underlined (i.e. increasing the intensity of river usages [2] leads to an decrease of the state of rivers ecology [1]).

After the evaluation process is finished, the sum within each row and each column was calculated. The sum within a row represents the sum of the active effects (AS) the variable has on the other variables. The sum within a column represents the sum of the passive effects (PS), how the variable was influenced by the others. The quotient (Q) of active effects to passive effects (Q = AS/PS) indicates whether the variable plays a more active role (Q > 1) or a more passive role (Q < 1) in the system. Finally the product (P) was calculated out of the sum of active effects and the sum of passive effects (P = AS•PS). The product (P) indicates whether a variable has a sensitive (high number) or buffering (low number) impact on the system.

The role of each variable in the system (5) is shown in **figure 1** and can be interpreted as follows. Some variables are highly active on other variables [active variables: 12, 16], while others are intensively influenced by other variables [passive variables: 4, 9, 15]. The active variables can not easily be influenced from inside the system, but they are sensitive levers of external effects. By this they are best suitable for the control of the system. On the other hand passive variables are perfect indicators. They should carefully be measured in order to investigate the state of the system. But impacts on the passive variables sometimes can be observed after a long time delay, when extreme situations may have already occurred.

Some variables are buffering since they neither influence others significantly nor are influenced by them [buffering variables: 1, 11]. These variables keep even after extreme changes in the system comparatively constant. But they also can be tricky, if their buffering effect depends on a time delay. In this case their impact on active variables should be investigated very carefully. On the other hand sensitive variables are intensively influencing other variables and are in the same intense influenced by them [sensitive variables: 6, 10, 18, 19, 20]. These variables are intensively bound into the network of the system. They can easily be used as a lever to increase the interactions and by this to change the system. But the lever should be used extremely careful otherwise the system might “explode” since the variable is linked to very many other variables. Finally there are some variables, which are somehow neutral in the system [neutral variables: 2, 3, 5, 7, 8, 13, 14, 17].

The cybernetic of the system (6) can be developed from table 1. All intense or very intense impacts (evaluation with “3”) and their direction were drawn in a network of control loops in order to image the cybernetic of the system. **Figure 2** shows the great number of control loops of the investigated system. It is nearly impossible to understand any systematic out of it. Consequently the control loops have to be separated in order to understand their dynamic.

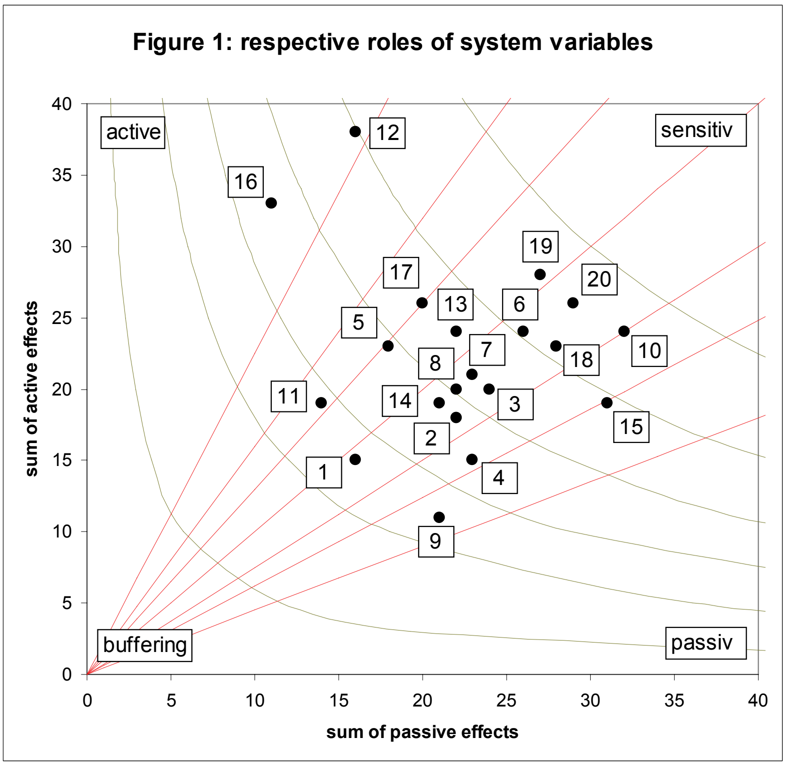

Figure 1 : respective roles of system variables

(1) state of river ecology
(2) intensity of river usage
(3) purification capacity of treatment plant
(4) amount of sewage sludge
(5) waste water production
(6) capacity of drainage system
(7) waste water charges
(8) efficiency of AZV-worker
(9) satisfaction of association members
(10) efficiency of AZV-management
(11) success of communication
(12) compulsion of laws and regulations
(13) intensity of catchment usage
(14) extent of mobility
(15) resource consumption catchment area
(16) availability of information technology
(17) grade of education
(18) quality of life for citizens
(19) economic power
(20) efficiency of political activities

The interpretation of the network of control loops can be distinguished in different stages as follows.

- Search after the very short control loops between two variables and interpret them on the background of the respective roles of the systems variables (figure 1). Search after longer control loops which are nested more and more and do a similar interpretation, but with the knowledge of the very short control loops. Step by step the cybernetic of the system can be understood.
- Distinguish between the positive and negative control loops. A positive control loop may build up extreme situations in the loop. A negative control loop is buffering internal and external impacts and is able to adjust the system. Negative control loops should be dominant in the urban water system.

- Develop a management strategy for the improvement of the system. In many cases it makes sense to define subsystems which cover the hot spots of the overall system, identified in the network of control loops.

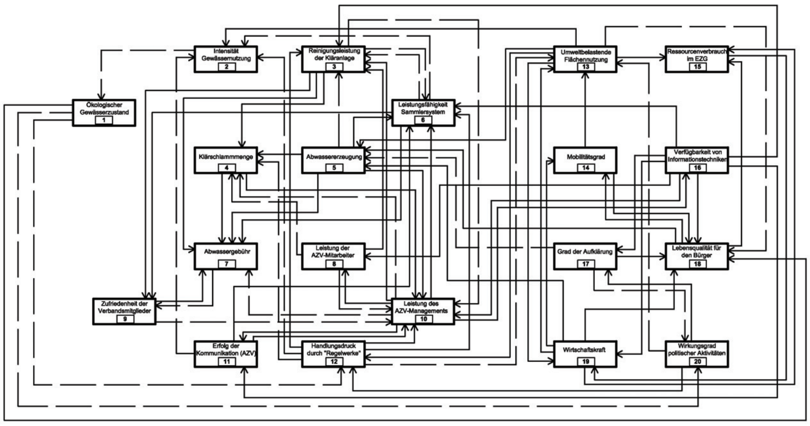

Figure 2 : network of control loops imaging the cybernetic of the system (full arrows = equally directed impacts, dotted arrows = inverse directed impacts)

5 GENERAL RESULTS OF THE CASE STUDY

The general results of this case study can be summarized as follows.

- The definition of the system (1) and the identification of variables (2) caused a better understanding of the system, forced a common "language" among the members of the team and reduced the number of misinterpretation.
- The matrix of variables (4) makes it possible to consider the diversity of the system, since variables can be technical ⇔ non technical, quantitative ⇔ non quantitative as well as rational ⇔ non rational ones. Although a single evaluation is fuzzy, a great number of evaluations make the picture sharp.
- The role of each variable in the system (5) gives everybody a clear view on the different interactions between the variables. The team members distinguish the active and passive as well as the sensitive and buffering variables in their understanding of the system now.
- The cybernetic of the system (6) lead the AZV-members to the awareness which control loops might be suitable to initiate changes. They understood the main hot spots of the system and decided to run the same model for the subsystem around the AZV-management, since this variable was the most significant one.

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