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PH.D. THESIS

GIS IN THE INDUSTRIAL ENVIRONMENTAL PROTECTION

The role of GIS in the improvement of environmental impact analyses

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I Preliminaries and goals of researches

In connection with the protection of our environment and the increasing industrial production there is a demand in many cases that the impacts of different activities in environmental protection should be easy to follow and to have influence on. To achieve this, companies adjust to management systems (e.g.: ISO 14001 Environmental Management System) which highlight environmental protection and help with decision making based on more detailed and complex data in accordance with environmental, social and human demands. To model the environmental impact they carry out a so called environmental impact and revision analysis that has detailed provision of law.

The author's aim was to develop an evaluating system suitable for environmental impact and revision analyses, that will initiate new possibilities – primarily by modelling the process of producing technical and medical gases. The obtained results are utilizable first of all for gas industry but other areas of industry can use them easily while keeping the rules of assembling and processing data. The system can be connected to other environmental management systems hereby helping the management what decision they have to make, what investments to effectuate and what activities to carry out in order to decrease pollution, especially in case of emergency with having the nature and the people's interest in sight.

Further aims of the dissertation:

- Using the pollution data in GIS, limitation of pollution in space, analysing the forms of geographical information for the management in a clear representation.
- Elaboration of evaluating rules for the different environmental elements.
- Conceptional analysis of Environmental Decision Support Systems.
- Elaboration of impact assessment of environmental elements, GIS possibilities, evaluating results.
- Developing a GIS method for a case study, than its expansion in general and emergency cases.
- Analysis of the system's dynamics in case of changes in environmental elements
- Elaboration of algorithm based on fuzzy logic for the analysis of information relyability, for making decision easier
- Comparison of the developed evaluating system and results coming from the use of fuzzy logic, critical analysis of divergence.

II. Research methods

Based on the known international and home experiments the author took some significant steps to improve an environmental impact evaluating system which is suitable for the examination of industrial and other establishments. The next step was to make definitions, to lay the foundation of modelling impact – and revision analysis and the spread of polluters, to show basic decision cases. The definitions were chosen from the internationally and at home mostly used approaches. Next the subject and active components of the examination were defined.

To develop the evaluating system it was necessary to establish a GIS database. The use of this database made each step significantly easier. The establishment of this data base were the following:

Choosing a GIS software suitable for assembling both vector and raster files. ESRI ArcVIEW 3.2 software was chosen which is suitable for carrying out the research with the help of inbuilt modules – geoprocessing module (deleting lines, dissolving features, clip, intersect, and union of themes), creation of buffers, calculating module for attributum charts, layout module for presentation.

For the evaluation system it is necessary to collect the data and sources. The author applied two methods. As a first step the pollution data of a hypothetical, planed plant were determined – based on generally measurable results – than a concrete case study, plant of Linde Gas Hungary in Répcelak. It happened by defining the concentration of polluting components with measuring (noise coming from operation, emission of air pollutant, contamination of surface water) and modelling (immision of air pollutants, noise coming from traffic). During modelling methods detailed in the dissertation were employed.

The accomplishment of logical operations and geographical analysing meant the use of the improved evaluating system, i.e. defining concentration-dispersion of environmental factors and different polluter components, forming layers then calculating the assigned values.

A colouring and ranging system, worked out by the author - and described in the dissertation - serves the presentation of the concentration-dispersion of polluter components, the environmental factors and the results. Concentration near or over the limit is indicated with the shades of yellow and red to show overstepping suggestively, while low concentration is indicated with green. This kind of colouring method can be explained as the colours of the traffic lights, meaning: red = danger, yellow = warning, green = appropriate. This method expresses suggestively the extent of pollution in the examined areas. At individual factors pollution which is over the limit or the total or several minor factors can be observed sharply.

In regard to methods it was an ambition to use and evaluate general, expansive data (planned plant) just as the application would be shown in a concrete case (Linde). Further aim was to develop a system which is adjustable to every polluter component so that the

concrete case study would not narrow down the possibilities of the evaluating system's application. It can be stated that to evaluate environmental impact in case of intended plants / events or a future activity of an existing plant is possible exclusively by modelling methods. When examining environmental pollution of an existing plant, results of concrete measurements can be taken into consideration. If there is no measurement or it is not representative modelling can be employed again.

To examine the reliability of the evaluating system became possible by having examined the modelling deficiency which arose from the reliability of data coming from the measuring instruments and the calculating methods.

The accuracy of data can be characterised in two ways, by the differences between the real and modelled values – the uncertainty – and by the dispersion describing the uncertainty – root-mean-square error. The other examination was the definition of Cohen-Kappa index by preparation of a misclassification matrix with taking a certain number of points divided at random. When examining the sensitivity, we were looking for an answer to the question: What changes can happen in the result if the used data and the centre of decision are changed?

To eliminate uncertainty deriving from the use of decision-making rules, and to avoid strong deviding lines coming from the Boolean-layers – since they are not typical in nature or pollution – the author used Fuzzy-logic based on mathematics during the examination of polluting components and environmental factors.

In case of common GIS the database is considered to be correct and within limit. With the help of the so called Boolean-algebra layers can be created within the hard decision making conditions and operation can be carried out in the database. When making decision these databases are usually not capable of representing the reliability of databases in connection of space, they can not handle probability values.

The fuzzy spatial analysis makes it possible to create categories much more suitable for human mind and language in contradiction to bistable decision making known from Boolean algebra. To create these categories we match a continuous function according to the type of the function when any point – on different probability levels – is acceptable for expressing the given answer.

After choosing the function needed for fuzzyfication the fuzzyficational operation can be carried out with ESRI ArcVIEW Spatial Analyst module on dispersion of all the polluters. As a result we get a set of membership values after matching each receptor with the number of polluters. These values are within the interval [0,1] of membership functions.

The author carried out the scientific analysis of results, divergences and comparison of results coming from Fuzzy-logic and the improved evaluating system. Two methods were applied. During the critical analysis just like the method (from general to concrete) that was used earlier in the case studies (planned plant – Linde Gas Hungary) a mathematical comparison was made between the differences of use of the two methods, as well as the obtained results. The index number that characterised the differences of values were dispersion (RMSE) volume.

A classification used by eveluating systems – not polluted, slightly polluted, medium-polluted, polluted, eztremly polluted – could be examined in case of both the planned plant and Linde Gas Hungary by preparing the misclassification matrix with the help of diagonally identical areas, accidental similarity and Cohen-Kappa index and by using comparative data of the similar areas´s proportion and the right class as well as the proportion of individual categories in the whole area.

III. Summary of the results

1. With a view of international and home special literature the dissertation gives a methodological summery of the possible decision supporting possibilities of GIS. The summary includes critical evaluation of each method and their practical application. We can say that at home and abroad the number of GIS application is increasing, they not only give a representation but help with complex environmental impact and revising analyses, going into the direction of developing decision-supporting system. Meanwhile it helps the decision making process with solving complex spatial problems. Parallel to the complexity there is a demand rising to treat different quantity and quality numerically in the system. Fuzzy-logic, which was used in ruling and controlling systems, is suitable to satisfy this demand. In the next few years integration of environmental impact and revision analysis, danger analysis and adaptation of Fuzzy-logic to this systems is expected.

2. Based on the international and home special literature IMPACT II was developed. During the development the author used the logic of DRASTIC method, that expresses the sensitivity of catchments basins, water bases, researches on strategic maps done in the capital, which work up city polluter's scattering and total effect. The bases of an urban environment evaluating system by humancentric approach called IMPACT developed by the author was used as well. IMPACT – as impact, the total of impact – is made up from the English name of the effect of the different environmental factors. Number II refers to the improved, refined version of the above mentioned urban environment qualifying system. The letters stand for the followings:

Imission of air pollutants
Main surfacewater quality indices
Pollution of noise
Affected under-surface water
Contamination of soils
Threat of other factors

I Imission of pollutants from point, diffuse, and moving sources.
M Contamination of surface water.
P Noise coming from operation of equipments, machines; and traffic.
A Contamination and spreading of pollutants in under surface water.
C Contamination of soil.
T Other factors: loss of flora and fauna, natural released radon from soil.

The evaluation system looks at the human and environmental viewpoints in a complex way. It can be connected to other environmental managing systems, so that it gives help to the management, what decision they have to make, what investments to effectuate and what activities to carry out in order to decrease, prevent pollution, especially in case of emergency with the interests of nature and people in sight. IMPACT II evaluating system gives the level of pollution respectively and the value that defines the quality of environment – that is IMPACT II index (I^{II}) itself. The evaluation system is suitable for using data of existing or planned (measured, modelled) sources, for survey of environmental conditions in existing plants, their temporary and permanent impacts (emergency), or environmental revising analysis, just as well as in the case of an intended plant – construction, operation and relinquishment. The I^{II} index can be expressed numerically and compared to former examinations so it is suitable for monitoring.

3. The author developed a method needed for calculating I^{II} index number. The number which shows the weight loss depending on the polluter component [W] and the values proportional to quantity, the factor depending on concentration [C] can be defined.

   To define of the danger index number [W] is possible with combining of Hommel danger indicate system with 44/2000 (XII.27.) EüM decree. This is suitable for a detailed, expanded for a large number of figures and numerical classification of danger for every clear component. For the not clear component - like solution, or any other, not easily explainable components, like the chemical oxigen demand (KOI) - is appropriate. With the help of this system is able to establish for every polluter, using in the evaluating system, the hazardity.

   The factors of polluters depending on concentration [C] can be characterised with a widespread saturation graph, which can be described with an exponential function. With the help of limit value, needed for the definition of the function´s value the λ, can be calculated for each polluter component. The factors that can not be examined with the above mentioned method –e.g. nature which is closely connected to all the environmental factors have another method developed.

4. The all out application of the evaluating system was shown in the dissertation with a case study. In the case of the planned plant there are probable emission values of polluting components– but matching the average measurable values. The definition of

the danger index number [W] and the concentration dependent factor [C], the method of converting GIS and the representation with colouring system can be followed.

After the introduction of the IMPACT II environmental impact analysis on a planned plant a concrete case study – Linde Gas Hungary Répcelak plant – was applied, its results are presented in the followings:

During the examination the plant was qualified by three environmental factors: air, surface water and noise. We can say about the company that it did not cause any pollution during proper operation to under surface water or soil, so exploration or assessment was not needed. Without specification other factors were not defined. It has to be mentioned that there are few plants or factories that can be referred to as ideal in connection of analysis which is connected to every environmental element and possesses measurements, numerical data based on monitoring system. We have to try to get the necessary data, examinations, explorations available for the evaluating system when we do complex, impact and revising analysis.

It can be generally stated that the evaluated are belongs to the not polluted, slightly polluted and in some extent to the medium polluted category. The medium polluted area is at the outgoing channel where the pollution of surface water, air and operating noise appear together. A similar problem arises from the collective appearance of operational-, traffic noise and air pollution at the southern corner of the plant and on a little part of the western part of the inhabited town.

The examination of the factors pointed out that it is primarily expedient to decrease the burden caused by noise and in surface water, because the level of these polluting components are close to the limit. With some intervention the IMPACT II index values referring to these areas could be significantly decreased.

Using this method the followings can be said:

The accuracy of the evaluating system's results depends on the used data, measuring and modelling results. We can use several modelling processes to achieve results, comparing them, but during modelling similar problems can appear. Only the length of the process would increase, accuracy would not change significantly. Besides the disadvantages, measure is suitable – with the economical aspects in sight as well – for controlling the model in an ideal setting at maximum one or two points, or a few components for a relatively long time.

If we examine only the results we can not see if the components exceed the limit or not, we can only see the collective pollution. Exceeding limits will be seen by the examination of each polluter component (that happens during the system's application) or later we conceptionally analyze the decision making situations.

We might be faced with further problems in case of evaluating smell-materials, because its level of recognition is much lower than the valid limit. The population is sensitive about this component while the evaluation is does not emphasise its significance. The spread of these smell-materials can be connected to air polluting components, so it belongs to the air environmental factor that is why – although it

could be applied – it is not recommended to put it into another category. We have the opportunity to increase the weight of the component, but this way we would lose the possibility to use the application of danger classification. The suggested method is to compare to the level of recognition when calculating the concentration dependent factor.

Following the possible changes (end of polluter emission, new measuring results, seeping/leaking in under-water) can be carried out by re-evaluation of components and factors, revising, overlaying, and by calculating the IMPACT II index, then comparing to the present situation.

Modelling a fictious damage in an existing dangerous plant and analysing the impacts of existing and possible polluter components could have high importance.

The results obtained from the application of the evaluation system do not deviate from the expected values, and elimination of the recognised deficiencies can improve the method.

5. With conceptionally analysis of decision supporting environmental information systems we defined the required processes that are needed to achieve the targets. We combined (multiplied) the decision weights and I^{II} index for this.

   Throughout the dissertation a solution was sought for a decision making problem, that have several targets and criteria, with the help of GIS instruments. The concrete targets were:

   - Provision of law, that is to make sure that pollution does not exceed the limit in the protected areas.
   - Minimalizing pollution with the economical aspects of continuous improvement in sight.

   From the criterions the limits of the polluters meant constraints, and the concentration-dispersions of the polluters were the factors.

   During the process over-limit values were defined in both cases. Than a these values and the areas of objects that need protection gave a specific area.

   To achieve the economical targets first an economic efficiency weight-set was defined to each environmental factor – with keeping the opinion of the decision makers in mind. To impoving the system these weights – shown in the example of Linde – instead of environmental factors, to the polluters were added.

   With combining (multiplying) the economic weight and IMPACT II index we come to amore unambiguous decision, subjectivism decreases and reliability increases.

6. The analysis of reliability of the data and results used in IMPACT II evaluation system was carried out as the method described in the dissertation. To define the system's accuracy, dynamics and sensitivity in case of changes in environmental elements the author suggested a method that changes the values and weight of polluter components.

   The deficiencies of the data used in the evaluation system (from different sources and different accuracy) are added up during the application of evaluating principles, they can strengthen or equalize each other. In the applied case studies the concentration dispersion of the different polluter components and the overlay of IMPACT II partial index were sum up, so it can be stated that as the first approach, the accuracy of application is defined by the least accurate layer. Since the base of the evaluation system is the weighed addition of the different layers the real accuracy is significantly better than the least accurate layer. That means that the applied evaluating system improves the accuracy of layers.

   When examining the sensitivity of the system the author was looking for the answer to what changes in the result can be found if the data and the decision weights are changed.

   First of all the examination started with rising the concentration of a polluter components over the limit. Than the whole evaluating process took place with the changed data, afterwards a comparison was made between the original numerical facts – during GIS evaluation the subtract of the layers – which showed the sensitivity of the system to changing the value of the concentration dependent factor [C].

   The alteration of the danger indicating number [W] was also the part of the analysis. A polluting component was chosen again when there were more than one examined components within the environmental factors, otherwise there would not be changes because of the normalization.

   The analysis showed that system responds more in case of changing the concentration dependent number [C] than changing the danger indicating number [W].

7. The author worked out algorithm with the principles of Fuzzy-logic to evaluate environment, the responsibility of information, based on the confidence interval of used data and prepare decision making mechanism easier.

   The execution of fuzzyfication, the establishment of sublayers was done by sigmoid membership function. The maximum level of pollution was calculated with fuzzy OR operation used on fuzzy layers, the average level of pollution with MEAN (arithm) operation, while the probable collective appearance of polluter were calculated with AND(*) operation within the interval [0,1].

   The data used in the .methods were the input data of the environmental factors of IMPACT II shown in the case study of the planned plant and Linde Gas Hungary Répcelak plant. These were the spatial concentration changes of the polluter components, their raster layers built up the sublayers of the fuzzy system.

The reliability of Fuzzy-logic based system depends on the reliability of data – e.g. accuracy of measurement. In most cases we know the accuracy of the measuring instruments or the divergence of data from the average of the measures. During the analysis of responsibility based on Fuzzy-logic – apart from the concrete value –the confidence interval was transformed from the accuracy data and the defining method to the confidence interval of fuzzy result was given.

The advanage of Fuzzy-logic is that it is extremly fast, does not restrict the number of input components, eliminates the uncertainties coming from weighing and additions. And another advanage is that it is based on mathematics which means no deficiencies burden it apart from basic uncertanties. It takes not only environmental factors into consideration but public complaints as well. The obtained results are numerical so it is easy to analyse the changes by comparing values.

8. The scientific analysis of results and divergencies, the comparison of result coming from IMPACT II and Fuzzy-logic was carried out. The critical analysis of divergence was done with the example of the two introduced case studies (planned plant, Linde Gsa Hungary), and with the comparison of the mathematical results and the differencies between the two methods. The dissertation shows the results obtained during the analysis of IMPACT II index and the OR operation of Fuzzy-logic. The mathematical index numbers characterising the differencies of values were: distribution (RMS), volume and standard deviancy.

   The comparison of classification stated by IMPACT II and applicable by Fuzzy-logic –not polluted, slightly polluted, medium polluted, polluted, extremly polluted- can be done with the matrix of misclassification, with the help of diagonically identical areas, accidental similarity and Cohen-Kappa index and by using comperative data of the similar areas´ proportion and the right class as well as the proportion of individual cathegories in the whole area.

   We can say that both methods are suitable for environmental impact analysis despite some divergence in their results. The dispersion of results0.15, the mean of volume 0,11, the mean of dispersion is under 0,055.Cohen-Kappa index is for the planned plant 30,57%, for Linde 64,62%. The difference comes from the fact that more examinations were carried out and the spread of factors covered each other more in case of Linde. The values from Fuzzy.logic are higher because of the examination of maximl pollution. IMPACT II method considers impacts depending on polluters as well, but using this method an evaluating specialist is needed. Only limits are necessary to apply Fuzzy-logic.

IV. The utilization of the results

The results of IMPACT II evaluation system can be used for different tasks when preparing environmental impact analysis, environmental economic decisions. They are suitable for using data of existing or fictious (measured, modelled) sources, for survey of environmental conditions in existing plants, their temporary and permanent impacts (emergency), or environmental revision analysis, just as well as in the case of an intended plant – construction, operation and relinquishment, i.e. environmental impact analysis.

The obtained results are utilizable first of all for gas industry but other areas of industry can use them easily while keeping the rules of assembling and processing data.

The evaluating system looks at human and environmental aspects in a complex way, it can be connected to other environmental management systems hereby helping the management what decision they have to make, what investments to effectuate and what activities to carry out in order to decrease and to prevent pollution.

It helps analysing the impacts of a fictious or real damage in an existing dangerous plant and makes it possible to decrease impacts and to prepare for any events.

To get the most punctual results there has to be an ambition to have all the necessary data – with required examinations - available for the evaluating system with all the environmental factors.

V. Publications in the topic of the thesis

Conference papers, scientific reports

- **Bogdán, O.** (1995): Traffic and noise pollution in city centre of Veszprém. TDK-essay University of Veszprém, Faculty of Technology of Chemistry. Veszprém.

- **Bogdán, O.** (1995): Traffic and noise pollution of Veszprém city. International Environmental Youth Conference Conference paper (pages 24-31). Mezőtúr.

- **Bogdán, O.** (1995): Report on GIS practise in surface modelling. Institute for Technology Ecosystem analyse, Mining University of Leoben, Austria.

- **Bogdán, O.** (1996): Studies on air pollutant impact on crop plants. Austrian Research Centre Seibersdorf, Austria.

- **Bogdán, O.** (1997): Surveying of environmental status of Veszprém by GIS. 3. Veszprémean Environmental Conference and Exhibition. Conference paper. Veszprém.

- **Bogdán, O.** (1997): Surveying of environmental status of Veszprém by GIS. VI. GIS in the Higher education Symposium Conference. Conference paper. Székesfehérvár.

- **Bogdán, O.** (2000): The environmental problems and investments if wood factory. Ligno-Novum Wood technology Exhibition. Conference paper. Sopron.

- **Bogdán, O. Füle L., Magyar I., Mógor E.** (2000): A map based environmental information system of LINDE GAS HUNGARY. Geomatikai közlemények III, 265-272. Sopron.

- **Bogdán, O.** (2001)**:** A „linfo" else environmental activities and the computer. Geographical Doctorand's VI. National Conference. Conference paper. Pécs.

- **Bogdán, O.** (2004)**:** The GIS tools of decision making. Gisopen National Conference. Conference CD. Székesfehérvár.

- **Bogdán, O.** (2004)**:** The GIS tools of decision making, national GIS Conference. Conference CD. Szolnok.

Verbal presentations

- **Bogdán, O.** (1995): Traffic and noise pollution in city centre of Veszprém. TDK-essay University of Veszprém, Faculty of Technology of Chemistry. Veszprém.

- **Bogdán, O.** (1995): Traffic and noise pollution of Veszprém city. International Environmental Youth Conference. Mezőtúr.

- **Bogdán, O.** (1997): Surveying of environmental status of Veszprém by GIS. 3. Veszprémean Environmental Conference and Exhibition. Veszprém.

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- **Bogdán, O.** (1997): Surveying of environmental status of Veszprém by GIS. VI. GIS in the Higher education Symposium Conference. Székesfehérvár.

- **Bogdán, O.** (2000): The environmental problems and investments if wood factory. Ligno-Novum Wood technology Exhibition. Sopron.

- **Bogdán, O. (**2001**):** A „linfo" else environmental activities and the computer. Geographical Doctorand's VI. National Conference. Pécs.

- **Bogdán, O. (**2004**):** The GIS tools of decision making. Gisopen National Conference. Székesfehérvár.

- **Bogdán, O. (**2004**):** The GIS tools of decision making, national GIS Conference. Szolnok.

Posters

- **Bogdán, O.** (1995): Traffic and noise pollution in city centre of Veszprém. TDK-essay University of Veszprém, Faculty of Technology of Chemistry. Veszprém.

- **Bogdán, O.** (1995): Traffic and noise pollution of Veszprém city. International Environmental Youth Conference. Mezőtúr.