# GIS ANALYTICAL TOOLS FOR PLANNING AND MANAGEMENT OF URBAN PROCESSES

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**Abstrakt.** Využití analytických nástrojů GIS pro plánování a řízení urbanizačních procesů.

Příspěvek je zaměřen především na popis a zhodnocení analytických nástrojů pro plánování a řízení urbanizačních procesů v prostředí GIS. Diskutovány jsou specializované programy a rozšíření a jejich nástroje využitelné pro modelování urbanizačních procesů. Část příspěvku je věnována zhodnocení současného stavu implementace těchto nástrojů do územně plánovací praxe.

Současné softwarové produkty (např. ArcGIS, GeoMedia, GRASS) disponují širokou škálou analytických nástrojů vhodných pro územní plánování. Dostupné a používané modely pro plánování urbanizačních procesů se věnují poměrně podrobně této problematice. Mezi nejznámější používané modely patří například model LUCIS (Land-use Conflict Identification Strategy), LADSS (Location-Allocation Decision Support systém), Geogracom 5W, UrbanSim (Urban Simulation) nebo MUSE (Method of Urban Safety Analysis and Environmental Design).

Většina hodnocených modelů a softwarových řešení je však typem „blackbox" modelu, který je sice snadný pro uživatele, nicméně žádný z nich není svojí funkcionalitou optimální pro využití v oblasti územního plánování.Proto je v článku představen koncept optimálního softwarového řešení pro snadnou implementaci do praxe. Koncept je zobrazen prostřednictvím schématu, které popisuje navržený metodický postup při plánování a řízení urbanizačních procesů.

Navržené programové řešení se skládá ze tří hlavních částí: modulu pro vstup dat, pro jejich analýzu a pro finální vizualizaci. Nejvýznamnější částí řešení je analytická sekce, která se dále dělí na 3 samostatné moduly: Modul scénáře vývoje, Modul pro analýzu konfliktů a Modul vyhledávání optimálních lokalit pro územní rozvoj. Výsledky analýz mohou být posuzovány samostatně, nebo mohou být zkombinovány do syntetického výsledku v podobě doporučení (návrhu) pro optimální využití krajiny.

**Klíčová slova:** územní plánování, urbanistické modely, rozvoj měst, analytické nástroje, GIS

**Abstract**.

The paper is focused especially on description and evaluation of analytical tools for planning and management of urban processes in GIS. Particularly special software and extensions and their tools useful for modeling urbanization processes are discussed. One part of paper is directed to evaluation of actual situation of implementation this tools into urban planning practices.

Actual software (e. g. ArcGIS, GeoMedia, GRASS) manage wide scale of analytical tools suitable for urban planning. Accessible models and models used for planning of urban processes are concerned with this topic very detailed. Between the most used models belong e. g. model (Land-use conflict identification strategy), LADSS (Location-Allocation Decision Support system), Geogracom 5W, UrbanSIM (Urban Simulation) or MUSE (Method of Urban Safety Analysis and Environmental Design).

The most of evaluated models and software are kind of “blackbox” model, which are easy for users, but anyone of them is not optimal for use for urban planning. That' s why the concept of optimal software solution for easy implementation into practices is introduced. The concept is shown through scheme which describes suggested systematic procedure of planning and management urbanization processes.

Designed software solution consists of 3 main parts – Module for data input, Module for GIS analysis and Module for data outputs and results visualization. The most important part is analytical part, which consists of 3 individual modules: Module Scenarios, Module Conflict Analysis and Module Optimal Areas. These results can be consider separately or can be combined into synthetic result – recommendation (concept) of optimal land use.

**Keywords:** urban planning, urban models, city development, analytical tools, GIS

## 1 Introduction

Urban process (urbanization) is mostly known as development and spontaneous change rural population into city population and development of urban settlement which is possible to regulate or even to plan. Town planning is very often based only on town planner' s experiences and estimations and not on results of spatial analysis, which are used very seldom. By using GIS methods is possible to identify unsuitable areas for urbanization and city development and so it is possible to aim the strategy of region development at other places.

Settlement evolution is not an accidental process, but process which can be managed and planned. For management of urbanization processes and for spatial and strategic planning of region development are GIS software used mostly only for creating outputs (mostly for printed maps). Analytical tools of GIS software, which have a great potential for use, are used very seldom and marginally. Sometimes there are used simple basic analytical tools, but mostly there exist no use of advanced spatial or network analysis.

Using GIS analytical tools brings into urbanization management of cities the methods based on scientific knowledge. Pursuant to knowledge of contemporary phenomena in territory is in

GIS software possible to propose optimal development of area to keep theses of sustainable environment.
Urban planners often solve spatial analysis only in their minds, based on their experiences and assessments. However this ideas should be applied on expert systems and on accurate methods too. Town planning is very often based only on town planner' s experiences and estimations and not on results of spatial analysis. One of the barrier is absent of high-quality and easy applicable methods. It means that that simulations and spatial analysis in GIS software are used very seldom.
For planning and management of urban processes is very appropriate to use sophisticated GIS methods which can be used as a tool for urban and strategic planning. By using GIS methods is possible to identify unsuitable areas for urbanization and city development and so it is possible to aim the strategy of region development at other places. Important part of planning process is to identify and evaluate suitable locations for new planned urban (human) activities. The simulation results of urban processes in studied area can be e. g. suggestions of several development scenarios and their comparison. If city planners will use these methods, more sophisticated policy of urban development can be applied.

## 2 GIS in urban planning

The urban planners use analytical tools of GIS software very seldom. The process of creating urban plans is mostly realized in CAD environment, which is used only as a tool for visualization. Proposals for land use changes are mostly based on experiences and estimations and not on results of spatial analysis in area of study.
In some foreign countries (USA, Germany, Canada), where GIS implementation has older history, implementation of GIS tools into urban planning is on the higher level. Urban planners use GIS software more commonly and so that their results are based on expert analysis. As a good example can be mentioned ArcGIS – Model Builder tool for regional planning of region around Munich, described by Schaller (2007). Second one (model LUCIS developed at the University of Florida) which is based on the same basics is described in capture 3.
Maantay and Ziegler (2007) introduce several examples of application GIS analytical tools for urban environment. Case studies focused on e. g. crime pattern analysis, community-based planning, urban environmental planning or urban services and urban populations are described in this publication. Spatial analysis and 3D tools are used very seldom, but the possibilities are great. Not only the visibility analysis or 3D display tools as a 3D flights can be used for urban planning and for projecting of city development. To use network analysis as geocoding, the traveling salesman problem, the vehicle routing problem or the shortest path problem is also possible and very suitable. For optimal planning of city development is necessary to know not only landscape preconditions and limits, but also inhabitant's needs. It can be applied in GIS environment as a analysis of people distribution in a space. This application describe e. g. Maantay and Ziegler (2007).
Contemporary technologies and contemporary distribution of cell phones allow relatively accurate location of every moving man. Thanks to data from GPS receivers from cars and other vehicles, can we have the data sets of a very high quality. This research activities was published by SENSEable City Laboratory in several papers (e. g. Pulselli (2005), Ratti (2005)). When the information about position of every inhabitant during day and night is known, it is possible to locate new activities and relocate old activities into better places. By the help of this data it is possible to concentrate urban development into optimal areas.

## 3 Analytical tools for planning and manage urbanization processes

Actual GIS software (e.g. ArcGIS, GRASS) manage a large number of analytical tools suitable for urban planning. Probably each GIS software with sufficient quantity and quality of tools can be used as a tool for land use planning. Particular GIS tools provide all of potential functions for planning and manage urbanization processes. Model LUCIS is a good example of combination GIS analytical tools into extension, accessible for urban planners. Free possibility of using GIS analytical tools show Kumar and Sinha (2006). Geographic Resource Analysis Support System (GRASS) was used in their research as a tool for urban planning.
It exist a barrier in the use of these tools, because the most of urban planners are not able doing with GIS. So that is necessary to create simple tools, which can offer many functions but simple operating. Following software and models introduce the most widely used and most important tools for manage urban processes.

### 3.1 LUCIS (Land-use conflict identification strategy)

Zwick and Carr (2007) introduce LUCIS (Land-use Conflict Identification Strategy) as a strategy to explore optimal suitability to three broad land-use categories (agriculture, conservation and urban) and compare them to identify where conflicts among them exist. LUCIS is also introduced as a tool with potential for many other applications, including strategic conservation planning, real estate investments, infrastructure planning or general market analysis.
The authors describe LUCIS as a GIS model that produces a spatial representation of probable patterns of future land use. The LUCIS approach is based on the work of Eugene P. Odum, presented in The Strategy of Ecosystem Development in 1969. Odum's model classifies all areas of the landscape into one of four types: productive areas, protective or natural areas, compromise areas and urban/industrial areas. For LUCIS model are used only three categories without mix category compromise areas. LUCIS compare this categories for determine objectively the limits between them in order to determine balances. Fig. 1 shows, that the results are compared to identify areas of potential conflicts or for identify areas suitable for various use.

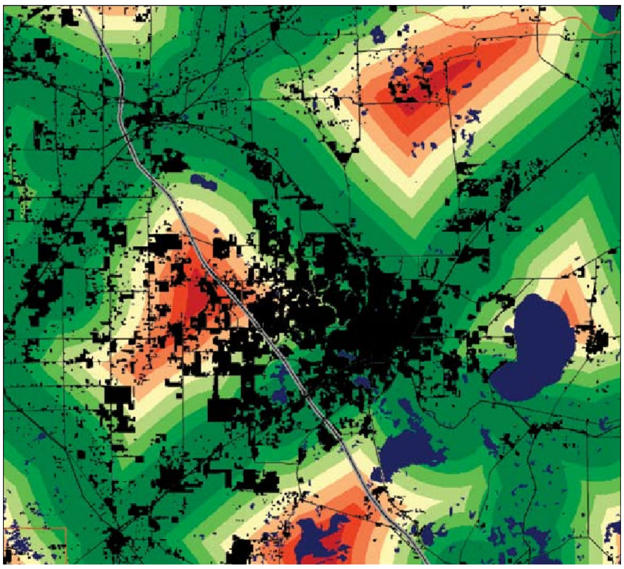

**Fig. 1.** Example of map results from LUCIS model (Economically suitable areas for industrial use) [22]

According to this knowledge the LUCIS can be divided into 5 steps: goals and objectives, data inventory, suitability, preference and conflict. While LUCIS uses base vector data, the analysis are primarily done with raster data. Model is represented in ArcGIS software as a tool created in Model Builder environment. It is possible to change some particular part of the Model, but bigger changes can not be done. It is expected that user have all data and there are no good possibilities to reduce some datasets. LUCIS combine only "static" data about urban and nature environment, but data about people's needs are not integrated.

### 3.2 LADSS (Land Allocation Decision Support System)

LADSS (Land Allocation Decision Support System) is a computer based land use planning tool developed by the Land Use Systems Programme of the Macaulay Institute. As the most of models interested in urban planning, this one is focused on the one direction of urban planning, rural land use planning.
LADSS is divided into several modules (Fig. 2) and one of them can be consider as a land use planning tool. Matthews (1999) write that land use planning tools has been implemented with the goal of supporting the search for land allocations that meet the goals of the land manager. The land manager initially defines the objectives of the search and makes any adjustments to the global or management parameters considered necessary to reflect the particular circumstances of the land managers holding. Model results show areas, their land use should be changed or allocated, what is the most important thing for urban planner.

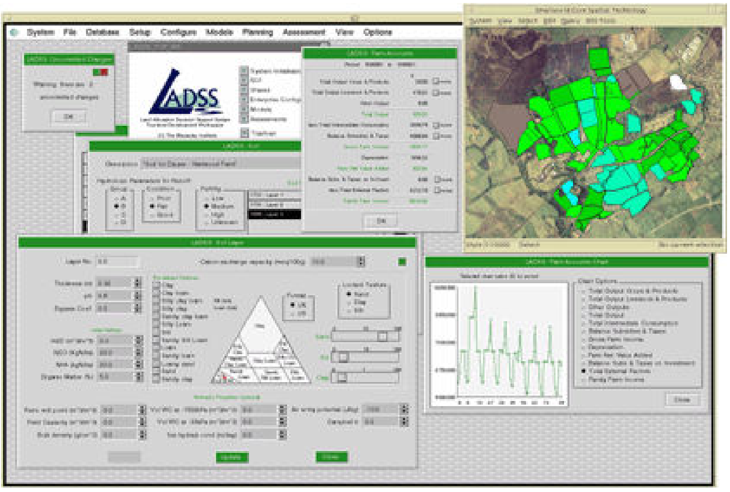

**Fig. 2.** Environment of the LADSS tool. [9]

### 3.3 Geogracom 5W

Bougromenko and Starosselets (1999) describe in their paper Geogracom 5W as the expert system with a database built on the knowledge of several transport specialists with the application of decision rules. Model is focused on development of transport network, based on data of contemporary traffic system. The result of the model should be information how to develop a transport network for all transport modes aiming at achievement of the strategic keys of regional development. According to the name "Geogracom 5W" system includes 5 main elements. The authors specify following elements:

1. assessment of the transport surroundings and determination of a minimal transport standard for the whole region (Fig. 3)
2. diagnosis of bottlenecks in transport development
3. generation of proposals aimed at elimination of defects potential emergency situations and achievement of a minimal transport standard
4. generation of alternative (depending on the selected criteria) investment programmes
5. evaluation of financial abilities and generation of proposals aimed at modification of tax policy and attraction of additional investments on the basis of appraisal of their effectiveness

One of the results of Geogracom 5W is recommendation to traffic network modification. But this is possible after re-location of urban objects. Transportation is one of the most important factors, which has great influence to creating new urban areas. Well connected areas have better potential for development than areas with normal or small connectivity. That is why this model has great potential for use in urban planning.

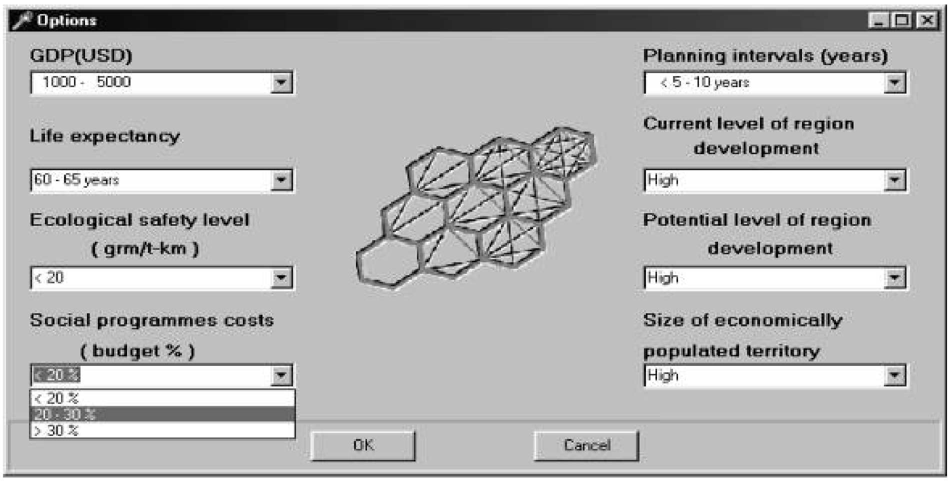


**Fig. 3.** Determination of a minimal transport standard [5]

### 3.4 Urban SIM (Urban Simulation)

Interdisciplinary research group at the University of Washington in Seattle develops Urban SIM as a software-based simulation model for integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy. In many articles (e. g. Waddel (2002), Alberti (2003) or Borning (2007)) are described basic principles of this software and model. Urban SIM software is licensed under GNU General Public License, which means it is free, open source software and can be changed for personal use.

By using the model several scenarios of landscape development can be created. Alberti (2003) describes that the model can be executed for a given scenario, and the results of one or more scenarios can be examined and compared. Urban SIM excels in it' s flexibility to disaggregate households, businesses, and land use. Urban SIM is a valuable tool for improving the level of understanding of how a metropolitan region is developing and how various combinations of land use and transportation policies and investments are likely to shape these trends.

It' s open source is one of greatest advantages of this software. It can be changed and adapt to specific needs of different regions and different users. One disadvantage can be seen in it' s complexity which can be the barrier for the most of urban planners who are not programmer's. Figure 4 shows the programming environment of the UrbanSIM model.

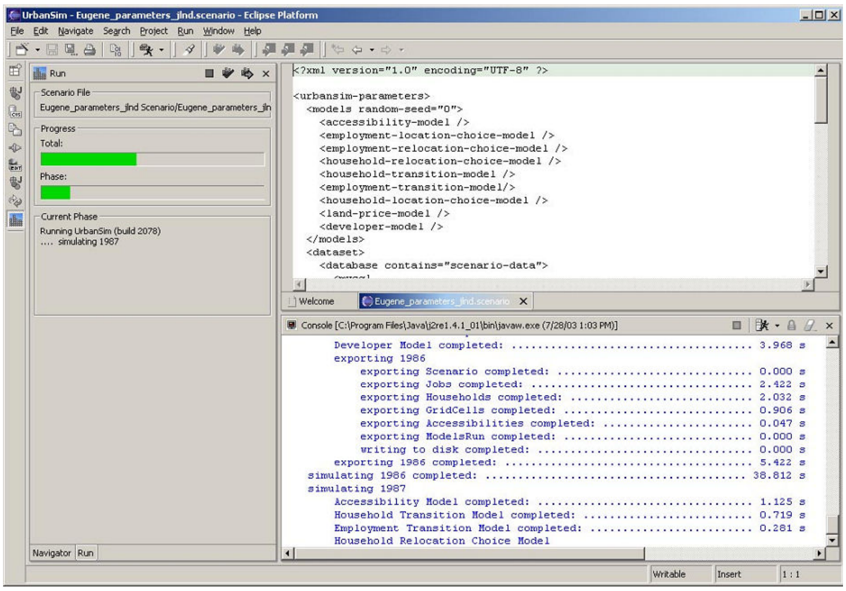


**Fig. 4.** Environment of the UrbanSIM model. [20]

### 3.5 MUSE (Method of Urban Safety Analysis and Environmental Design)

MUSE (Method of Urban Safety Analysis and Environmental Design), is based on the theory of The Image of the City by Lynch (1961), and some urban physical elements are defined as parts of an organic system (Murao, Yamazaki (1999)).
The authors describes MUSE as a method of analyzing, designing and simulating a city, in which urban physical elements are defined as parts of the organic system in GIS. The method works with followed five types of elements :

- paths - linear elements on which people can pass, such as like streets
- edges - other linear elements which people cannot cross, like coasts
- districts - areas that people recognize to be identical
- nodes – point elements, important intersections and important cores (Fig. 5)
- landmarks


**Fig. 5.** Cores as point elements of the MUSE model. [15]

This system consists of three fields, namely, Semantics, Syntactic, and Pragmatics. Semantics is the field in relation to the classification and the definition of spatial data. Syntactic deals with the relationship among the spatial data and other elements (i.e., time, location, and social systems). Pragmatics is the field in connection with the application of the information to the real social life for people (Murao, Yamazaki (2000)). Primary MUSE was developed for early damage assessment systems as a tool to analyze a city from the viewpoints of urban safety. Because it's software solution is based on ArcView 3.x and on 3D and spatial analyst, it can be changed and applied to more elements of urban systems.

### 3.6 SUDSS (Spatial Understanding and Decision Support System )

Jankowski and Stasik (2001) describes SUDSS as an Internet-based software prototype for a series of experiments in space and time distributed collaborative work environment. The software is focused on simplified interface design and accessibility without space or time constraints. Jankowski and Stasik formulated their software prototype for land-use zoning, resource management, and policy development. SUDSS is based on ESRI Map Objects and combines vector and raster data.
The main part of the structure is the separation of available functions into two levels of difficulty. A decision-maker with no GIS experience (low level of difficulty) can start with simple buttons that enable access to information, expressing opinion, changing session constraints (request) and evaluation. Users with greater expertise can use drawing, spatial analysis, commentary functions or multiple criteria evaluation (Fig. 6).
It' s unusual functions as a multi-user voting possibilities or multi-user interactive evaluating can be consider as a good step to create optimal analytical tool for decision makers. SUDSS is a good example of software, which can be used by people with no special skills. But it's advanced functions can be used by experts, who are able using it correctly. However the development of SUDSS is finished and it' s online version in not accessible.

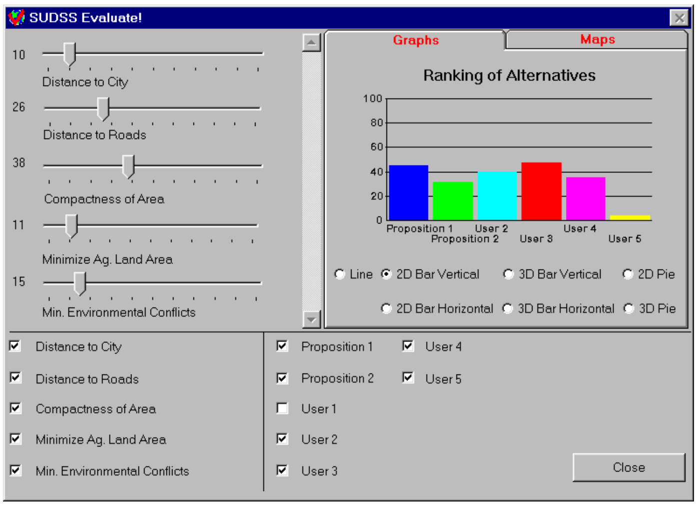


**Fig. 6.** Evaluation window provides the necessary functions for multiple criteria evaluation of alternative land use plans. [7]

## 4 Concept of optimal software solution

There exist several tools and software used for urban planning. No one of them is a software for routine use, what is necessary condition for the most of urban planners. Robust high-quality and wide-spread software for urban simulations is missing. The development of several software solutions was stopped because they were not used in practical application.

Therefore optimal software should be enough complicated for the best results but it should be simple for use on the other hand. One of the best way to distribute software to the most of users is to provide it free and through Internet. Typical example of this solution is ArcGIS Server, which offer through Internet technologies almost the same functions as desktop solutions. This concept could be implemented into urban planning and decision making too.
The most important factor of the whole software solution should be the possibility of interactive entry into model and possibility of it' s changes and modifications. The body of all spatial analysis should be multi-criteria evaluation of separate factors, which have their influence on creating urban landscape. It should be possible to interactive change the weights of separate factors, which determinate the results of analysis. The most important thing is to have all relevant data, which are relevant for studied area. Software should be "multi-user". It means that users of this software could be not only urban planers and other experts, but also common people, developers or policymakers. For each of them should be created thin or fat client with simple or advanced functions. Expert should be able to input and change more parameters than the common people. This idea of optimal software solution is shown on the Fig. 7. The scheme divides whole software solution into three main parts:
1. Module for data input
2. Module for GIS analysis
3. Module for data outputs and results visualization

## 4.1 Module for data input

This module should be able to load data from several sources. The data sets are divided into 3 categories (1. data about human activities – data about industry, agriculture, transport, population, GPS or GSM data about movement of vehicles and inhabitants, statistic data from census, data from several registry 2. data about actual land use – urban plan, aerial photo, 3. data about landscape preconditions – geology, soils, clime, DEM, protected areas, etc.). This categories should be connected because some kinds of data belong to two categories. This 3 modules should involve all relevant data for determination of optimal urban development.

## 4.2 Module for GIS analysis

The main part of optimal software solution is analytical module, containing 3 parts – 3 separated sub-models. The data input into this analytical module with some conditions and rulers, created by author as default rulers (e. g. general ruler to unable to plan human activities in flooding areas). This default rulers should be predefined and they should be changed only in abnormal situations. Second group of condition involved rulers which is necessary to input by user (pixel resolution, weights of some factors, disputable factors). Because some areas are abnormal, it should be possible to change all weights and all factor to obtain optimal conditions.
Module for GIS analysis should consist of followed sub-models, which can run together or separately (according to input parameters).

Module Scenarios
This sub – model allows to create possible scenarios of urban development. For this module is necessary to input information about factors, which has influence to land use changes (increasing population, to little shopping centers, highways defects, flooding, etc.).

Module Conflict Analysis

This sub – model allows to search areas, where some human activities (actual and planned) are in conflict with landscape preconditions (human activities in protected areas, in flooding areas, in landslide areas, etc.).

Module Optimal Areas
This sub – model allows to find optimal places for planned human activities. User inputs are requested area and requested type of activity (area for sport, for industry, for shopping center) and the result is optimal area for this activity. This part should be accessible not only for urban planners and experts, but for developers and common people too.

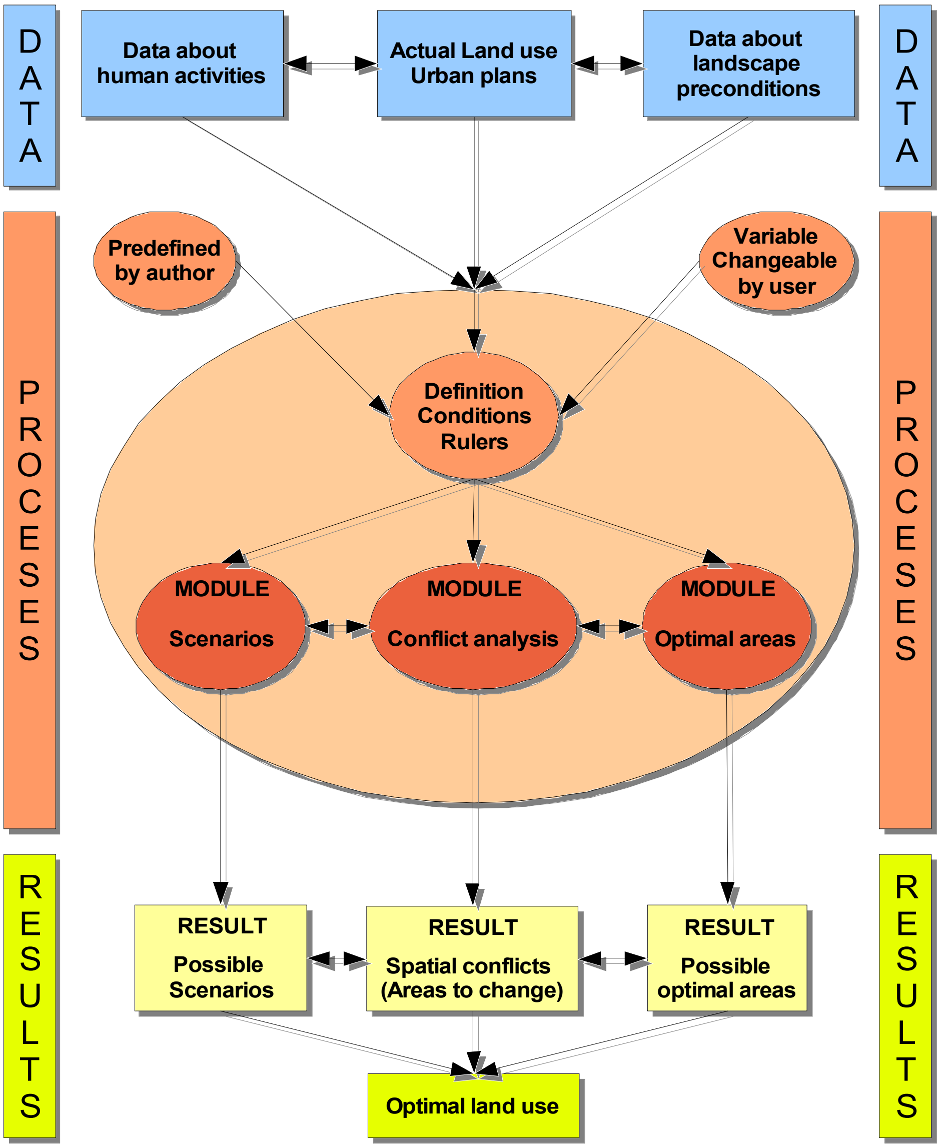


**Fig. 7.** Scheme of the optimal software solution

### 4.3 Module for data outputs and results visualization

The last module provide 3 separate outputs:
1. Result – Possible scenarios as a result of Module Scenarios

2. Result – Spatial conflicts (Areas for land use change) as a result of Module Conflict Analysis
3. Result – Possible areas (Optimal areas for new planned activities) as a result of Module Optimal Areas

The first group of results (possible scenarios) should be the tool for modeling possibilities of urban development. This result should be good for urban planners who can decide which solution of city or landscape development will be the best. The second result (spatial conflicts) shows all potential conflicts between human activities and landscape preconditions. This information should be used for land use changes. The last group of results should be areas, where is possible to realize new human activities without landscape damage. Suggested areas should be the most optimal areas for urban development.

In some cases is better to use only one separated result, but in some cases is necessary to use all possible result of analysis. That's why, the results can be consider separately or can be combined into synthetic result – recommendation (concept) of optimal land use.

## 5 Conclusion

The paper describes the most important and more interesting urban models, implemented into several software solutions. It was described 6 software solutions and mentioned several others. Each of this software has it' s advantages and it' s disadvantages. Some of them are just finished project but some of them are in progress. No one of mentioned software is the optimal software, that could be wide spread tool between urban planners. That' s why the concept of optimal software was created. Only by using spatial analysis can be urban planning and urban development more expert area of study and the results and decision can be better, more quickly and more optimal. By creating simple and easy software for urban planners, experts, policymakers, developers and common people, the urban planning can be more effective.

## References

1. Alberti, M., Waddell, P.: UrbanSIM--A Tool for Land Use Planners. *Georgia Basin/Puget Sound Research Conference.* Vancouver, 2003.
2. Batty, M., Densham, P. J.: *Decision support, GIS, and urban planning*. London. Centre for Advanced Spatial Analysis, University College London, 1996.
3. Borning, A., Waddell, P., Förster, R.: UrbanSIM: Using Simulation to Inform Public Deliberation and Decision-Making. *Digital Government: Advanced Research and Case Studies. Hsinchun Chen et al. (eds.)*, Springer-Verlag, 2007.
4. Bougromenko, V., Starosselets, A. (2000): Demonstration of Geogracom 5W - an expert system for transport strategic planning. *European transport conference*. Cambridge, 2000.
5. Bougromenko, V., Zakirov M.: Geogracom 5W - expert system for sustainable urban and regional transport development. *CUPUM '99 Computers in Urban Planning and Urban Management. On the edge of the millenium*, Venice, 1999.
6. Burian, J.: Analýza konfliktů přírodních podmínek s využitím území Mikroregionu Hranicko. *Sborník přednášek z 1. národního kongresu geoinformatiky v Česku – Geoinformatika pro každého*. Mikulov, 2007, CD-ROM.

7. Jankowski, P., Stasik, M.: Design considerations for space and time distributed spatial decision making. *Journal of Geographic Information and Decision Analysis 1(1); 1-8. Accessed Mar. 3,* 2001.
8. Kumar, V. R. , Satya, A. V. , Sinha, P. K.: Urban Planning with Free and Open Source Geographic Information system. *Geological Survey of India, Southern Region*, Hyderabad, 2006.
9. Land Alocation decision Support System [online]. c2007, last revision 2007 [cit. 2007-11-5]. <http://www.macaulay.ac.uk/LADSS/>.
10. Laurini, R.: *Information Systems for Urban Planning*. London and New York, 2001.
11. Matthews, K. B., Sibbald, A. R., Craw, S.: Implementation of a spatial decision support system for rural land use planning: Integrating GIS and environmental models with search and optimisation algorithms. *Computer and Electronics in Agriculture 23*, 1999.
12. Maantanay, J., Ziegler, J.: *GIS for the Urban Environment*. ESRI Press, Redlands, 2007.
13. Murao, O., Yamazaki, F.: Use of GIS for the Method of Urban Safety Analysis and Environmental Design. *Proceedings of the 20th Asian Conference on Remote Sensing, Vol. 2, 951-956*, Hong Kong, 1999.
14. Murao, O., and Yamazaki, F.: Prospect for the Method of Urban Safety Analysis and Environmental Design. *Proceedings of the 21th Asian Conference on Remote Sensing, Vol. 2, 951-956*, Hong Kong, 2000.
15. Murao, O., Yamazaki, F.: MUSE (Use of GIS for the Method of Urban Safety Analysis and Environmental Design). *Arc Review*, Redlands, 2000.
16. Odum, E. P.: *The strategy of ecosystems*. Van Nostrand Reinhold, New York, 1985.
17. Plšek, V.: Analýza výškových poměrů města. *16. konference GIS ESRI a Leica Geosystems v ČR*. Arcdata Praha, 2007.
18. Pulselli R. M., Ratti C.: *Mobile Landscapes*. Equilbri (Il Mulino), 2005.
19. Ratti C., Sevtsuk A., Huang S., Pailer R.: Mobile Landscapes: Graz in Real Time. *Proceedings of the 3rd Symposium on LBS & TeleCartography*. Vienna, Austria, 2005.
20. Schaller, J..: ArcGIS – ModelBuilder Applications for Regional and Development Planning in the Region of Munich (Bavaria). *16. konference GIS ESRI a Leica Geosystems v ČR*. Arcdata Praha, 2007.
21. Urban Sim [online]. c2007, last revision 2007 [cit. 2007-11-5]. <http://www.urbansim.org/>.
22. Waddell, P.: UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. *Journal of the American Planning Association. Vol. 68 No. 3*, 2002.
23. Zwick, P. ,Carr, M.: *Smart Land-Use Analysis, The LUCIS Model*. ESRI Press, Redlands, 2007.