Soft Anticipatory Computing for Spatial Decision Support

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Abstract
Geographical space is modelled according to main principles of systemic modelling and the anticipatory paradigm. In this way a computer based prototype supporting spatial decisions and the management of the physical environment is established. In using the prototype with real world historical data it is demonstrated that an anticipatory approach may ameliorate spatial planning and decision making. However, before being fully operational the model has to be improved in several ways. Further, attitudes, insights, and working skills of the physical planners and decision-makers have to be improved in order to take full advantage of the anticipatory approach.
Keywords: Systemic Geographical Modelling, Soft Anticipatory Computing, Spatial Decision Support, Spatial System Simulation, Territorial Concern.

1 Introduction

Geographical space (GS), seen as a three-dimensional Euclidean space, is a common physical space for all concrete systems, living as well as non-living ones (Miller, 1978). This means that everything any human being, or any group of humans, does in that space will affect our common living environment, and hence, directly or indirectly having an impact upon all of us. Consequently, a good management of our common GS will be of paramount importance for a sustained life on earth.

However, our current management of GS is far from perfect. Daily we hear from natural catastrophes, technical accidents and environmental disasters. Factors that aggravate the situation may be found in the planning and decision support systems applied for managing decisions and actions concerning the GS. A majority of those support systems are based on the reactive paradigm (Rosen, 1985) and the classical two-valued logic of an abstracted and idealized world (Kosko, 1993). So far, modern research in anticipatory computing, fuzzy logic, and soft computing unfortunately has not to any significant extent been applied in geographical management systems.

Hence, the purpose here is to build and assess a prototype of a Soft Anticipatory Platform (SAP). The objective of SAP is to support planning and managing of the GS. SAP is a computer tool based on soft anticipatory computing and systemic spatial modelling and simulation. The approach in this paper is mainly practical while Asproth and Håkansson (2002) take a more theoretical stance.

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2 Theoretical Base for the Design of SAP

The design of the Soft Anticipatory Platform (SAP) will be based on a set of earlier research findings. Those results will here be identified and the conclusions for SAP will be drawn.

2.1 The Territorial Concern as an Anticipatory Arena

Geographical space may been identified as a Territorial Concern (TC). A TC, as outlined in figure 1, being a community based organisation for the design, construction, and maintenance of a territory, i. e. a geographical region (a space) with all the living creatures and non-living objects residing within its boundaries. In other words, a TC is a community, i.e. a living system, with the responsibility (the concern) to establish and maintain a satisfactory configuration of system components and processes and to keep a set of essential variables within critical levels (Holmberg, 1994). This also means that the TC is a homeostatic system in the meaning of Cannon (1939).

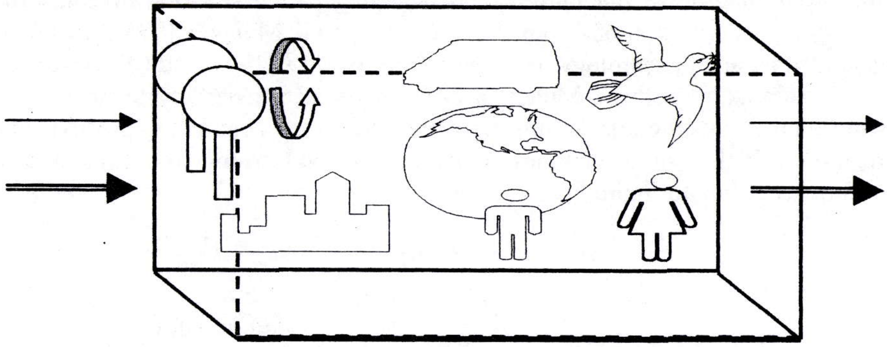

Fig. 1: A Territorial Concern is a geographical space with the responsibility for all living and non-living objects and their processes within its boundaries.

Hence, the TC within its boundaries will embody a huge set of highly interdependent flows and processes. Material, Energy and Know-how according to Boulding (1978), drive those. To this, I want to add Space, Time and Infrastructure as important supporting entities, se table 1. Each of those will be discussed in the following.

Table 1: Entities supporting the TC

1. Matter and material
2. Energy
3. Know-how
4. Space
5. Time
6. Infrastructure

The multi-actor and multi-process character of the TC will make it more or less impossible to define and establish an absolute optimum (Ekeland, 2000). However, it is always possible trying to ameliorate the situation according to the Resources, Rules, Risks, and Restrictions currently at hand.

Hence, even if due to high complexity far from everything in the TC is understandable or perceivable, it is always possible to interact with that complexity. Such an interaction may here be seen as a learning activity helping us to improve our understanding and decision making capability. To the degree that interaction may be restricted to a model, i.e. the SAP, the negative consequences of bad decisions and actions will also be eliminated.

2.2 Anticipating with Systemic Modelling

The conclusion of synthesising the modelling thinking of Van Gigch (1991), Le Moigne (1995), Rosen (1985) and others is that modelling is an ongoing and never ending process. The model may not be conceptualised as a static tool but more as a dynamic representation of our current understanding of the situation or entity under study. Further, according to both van Gigch (1991) and le Moigne (1995), modelling is always guided by an epistemology. Here, von Glasersfeld's (1998) radical constructivist theory in combination with Le Moigne's (1995) approach toward systemic modelling seems to be an interesting and promising alternative to the dominating positivistic and analytical ones. In this way we will arrive in a continuous learning process or modelling relationship according to figure 2.

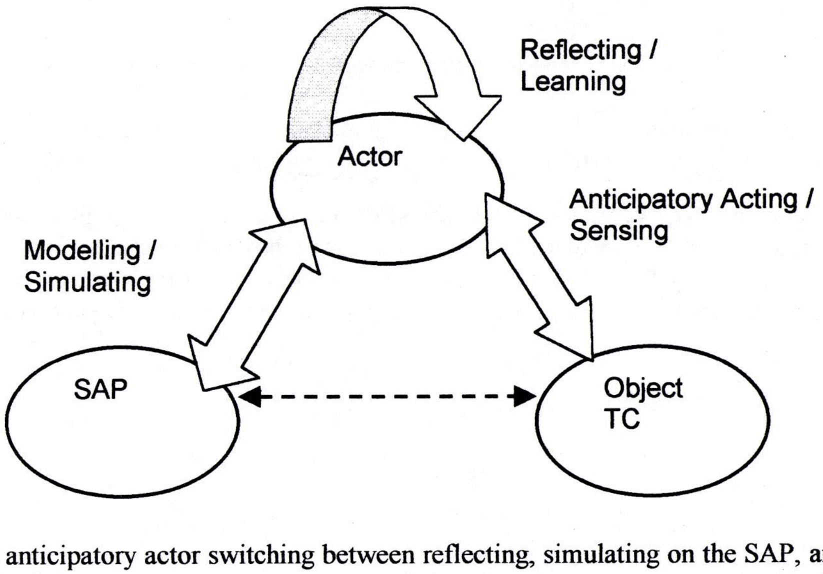

Fig. 2: The anticipatory actor switching between reflecting, simulating on the SAP, and acting on the TC.

With this approach influenced by the ideas of systemic modelling, the anticipatory actor and modeller becomes visible. Hence, there is no doubt that an anticipatory simulation run of the model is both more effective and less dangerous than an unguided and more or less random acting on the real object. Here obviously the three main spheres of figure 2 also have an interesting parallelism with Popper's (1979) three worlds.

Anticipation may be seen as building universal abstractions and developing abstract ideas and concepts (van de Vijver, 2000). SAP is aiming at facilitating that activity. Hence, the model may never be finished or closed. It has to be continuously changed and developed in pace with the modeller's increasing insights and deepening understanding. Further, with this conception the connection between anticipatory modelling and computing and Simon's (1998) design science becomes evident.

However, even if guided by a systemic modelling approach, the model will result in a set of variables and relationships and constraints among them. This means that the variables realised in the model will be just a small subset of the infinitely many possible ones. Hence, even here reconstructability analysis in the meaning of Klir (1991) will be an enormously important task. That will therefor be a major part of the learning process.

2.3 Anticipating is Acting

Dubois (2000, 1998a-b) has at repeated occasions stressed the difference between anticipation and prediction but also between anticipatory systems and classical control theory. Although the distinction is utterly crucial, yet, the concepts are often intermixed and used, more or less, as synonymies. Nevertheless, anticipation is a much richer and all encompassing concept than prediction. As can be seen in figure 3, anticipation, with all the steps of the anticipatory loop (AL), includes several activities. Of those acting may be seen as the most important and discriminating one. Hence, the system acts at time **t** in order to be in as good a position as possible at a later time instant (**t** + **i**). That acting may be based on a prediction. Nevertheless, such prediction is just one part of the AL, i.e. without anticipatory acting it is not relevant to speak about anticipation at all.

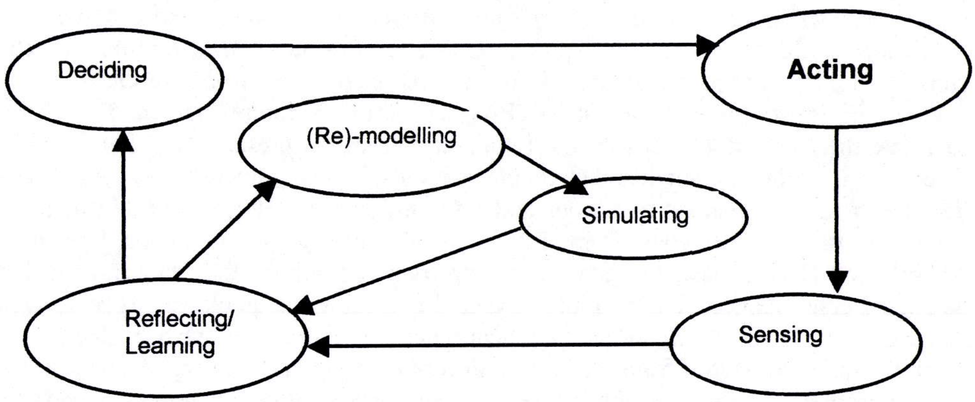

Fig. 3: Phases of the Anticipatory Loop (AL) resulting in acting.

Further, according to figure 4, those anticipatory actions can be divided into four sets. First, possible actions (PA) are all the actions the system in focus (SF) may take at a certain time instant. Second, conscious actions (CA) are those actions the SF is conscious of. Often CA is much smaller than PA. It may also be the case, as can be seen from figure 4, that SF juges an action as possible even if it falls outside of PA. A last distinction is between actions that in the actual context are favourable actions (FA) and harmful actions (HA) respectively.

Hence, the main task of a SAP artefact aiming at increasing its system's anticipatory power will be to discriminate between FA and HA. It also has to increase the size of CA. Accurate predictions may in many cases be of less interest. This observation has an interesting relation with Klir (1996a), who discusses the trade off between relevance, complexity, and uncertainty.

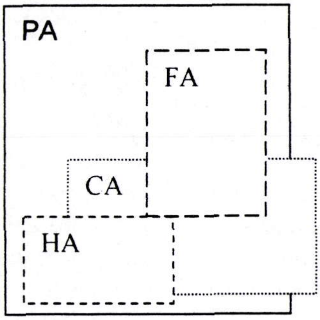

Fig. 4: Relations between Possible (PA), Conscious (CA), Favorable (FA), and Harmful actions (HA) in anticipatory systems.

Further, Dubois (1998a-b, 2000) has defined externalist (Exo-) and internalist (Endo-) anticipation. In this context it may be worthwhile to make further distinctions. First, with Exploratory or Evolutionary Anticipation (EA) we understand a model and a computer simulation in order to explore possible future states and to find the probable consequences of alternative actions. Here the time arrow goes from present to future. Second, in Prescriptive Anticipation (PA) we define a future state and tracks or calculate the path, which goes to that future state from the present state. For example, when the US government decided to put a man on the moon (a future state), that decision trigged a great set of actions and activities over a long time period (the path). Here the time arrow goes from future to present. In Inhibitory or Preventive Anticipation (IA), at last, the goal is to help us avoid actions that may have bad or damaging consequences. For example, to take the window is a quick way to go down to the street but we refrain as we can anticipate that the landing may be a bit hard. Here again the time arrow goes from the present toward the future (Holmberg, 2000).

One problem, however, which still lacks an acceptable solution is how to express the actor's will in the modelling and anticipatory simulation runs. Deterministic systems can be handled with recursive methods. With incursion and hyperincursion the range of applications will increase but there still is no good way to handle a system, or an actor, with a free will and an open mind which may learn and develop its insights. Weaver (1948) has defined three types of systems, i.e. systems of organized simplicity, systems of disorganized complexity, and systems of organized complexity. Here we seem to have an interesting similarity. Deterministic systems and recursive methods correspond to organized simplicity. Chaotic systems and disorganized complexity can to a great extent be handled with incursive and hyperincursive approaches (Dubois, 1998a).

However, coming to organized complexity and free will, there still seem to be a lack of suitable methods. Perhaps we here can identify something between deterministic and chaotic systems, in the same way as we have organized complexity between organised simplicity and disorganized complexity. Those systems may be called Finalistic systems according to a finality principle. Hence, SAP, if possible, even has to handle such finalistic anticipation (FA).

At last, Nadin (2000) has argued for an anticipation based on a relational mathematics. Hence, an extension of the computational approach with a relational one seems to be very promising. Perhaps with such an approach it would even be possible to handle systems of organized complexity and finalistic systems with a free will. However, such a relational approach has to be postponed to later releases of SAP.

2.4 Multimodality for Soft Early Warning

As already said, within a TC, homeostasis will be of paramount importance. In order to guarantee sustainability, it is crucial to detect any trends, which threaten to drive a critical system variable out of its range, as early as possible. This because it normally is more easy and requires less energy to reverse such a devastating trend at an early stage. In this context a Multi-Modal approach may be of great help.

The Multi-Modal Systems Method (MMSM), as developed by JDR de Raadt (2000), is a means for grasping the full width of human life and any human activity system. The main idea being that for any socio-technical system to develop in a positive way all its modalities have to be considered in a balanced way. Contrary, if some modalities are constrained while others are overemphasised the system will express malfunctions and retrogression. MMSM may be seen in contrast to conventional well-established sciences, which normally is focused on just one modality. According to MMSM, this will lead to a biased view of the phenomena under study. A varying mix of deterministic and normative laws governs each modality in MMSM. This constitutes another interesting parallelism with deterministic, chaotic, and finalistic anticipation.

A MMSM-approach may successfully be applied for anticipatory purposes in business firms and other socio-technical or human activity systems (Holmberg, 1999). Interesting, from an anticipatory point of view, is that higher modalities work as indicators for the later outcome of the lower ones. Used in this way, MMSM may serve as a Soft Early Warning System (SEWS). Hence, thanks to SEWS indications, it will be possible to act, i. e. to anticipate, as soon as any variable tends to go outside of its critical boundaries. Figure 5 also highlights the basic systems idea that it is better to act against the causes instead of against the symptoms.

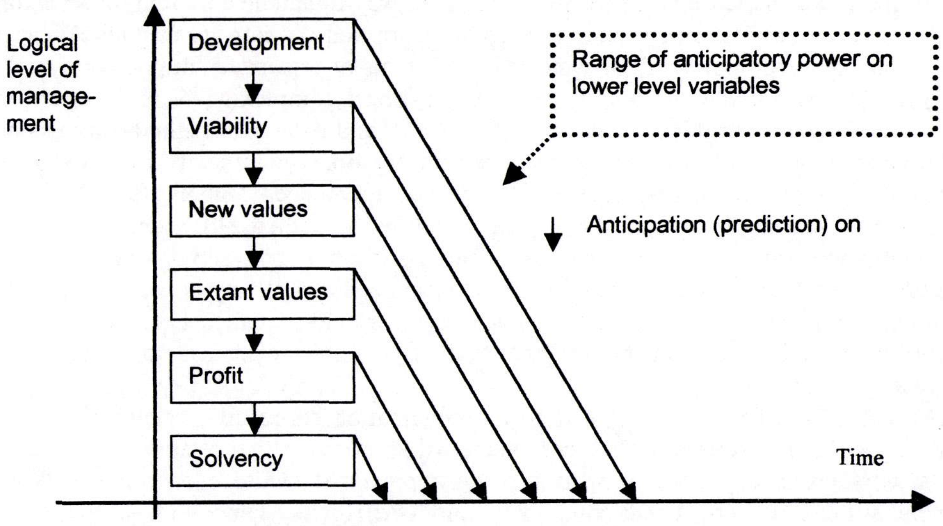

Fig. 5: Anticipatory power of control variables at different levels of management (Holmberg, 1999).

2.5 Soft Computing for Dealing with Reality

Klir (1996b) has characterised soft computing (SC) as an emerging new branch of computing, which exploits tolerance for uncertainty, robustness, and low cost. In SC approximate rather than precise solutions are prefered. SC is inspired by natural systems and the challenge is to find acceptable solutions to messy real world problems rather then finding exact solutions to abstracted and formalized ones.

SC feels as a natural choice for SAP as the territorial concern (TC), as well as the concrete real world at large, is continuous (Miller, 1978). For example, the landscape continuously changes from flats to hills or cultivable land gradually changes into sterile ground. Further, if we choose to express the TC as a system model, the system state of that model will be expressed by the values of a set of system variables (Klir, 1991). Hence, in order to express the continuous character of reality those system variables also ought to be continuous. This is a bit contradictory to classical bivalent logic but fits very well with modern fuzzy or multivalent logic (Klir and Yuan, 1995) and the fuzzy principle, i.e. "Everything is a matter of degree" (Kosko, 1993).

2.6 Decision Making Under Uncertainty

Holmberg (2000) and Asproth et al (2001) discuss the type of decision making in focus here. Hence it may be concluded that a TC is a socio-technical system (STS), i.e. a level eight system according to Boulding's (1956) taxonomy of system classes with increasing complexity. Consequently, the very special requests that fact will put on the modelling and computing activities have to be met. First, being a system on level eight implies a high complexity with many emerging new system properties. Therefore, the decision-maker will never be in full control of the system. It will, at least to some extent, take on a life of its own. It will express self-organisation and autopoiesis (Mingers, 1995), i.e. the system can never be designed with full control as a technical device on Boulding's level two or three. The best we can hope for is to guide the system in a generally positive direction according to the ideas of Soft System Methodology (Checkland and Scholes, 1990). This is also in line with what has already been said about the TC as being a system governed by both deterministic and normative laws.

Coming to TC as an autopoietic system, Atlan (1979) has pointed out that such systems must be able to adjust or change themselves without external input. Further, our TC is not the only system in the actual universe. It will be woven into a web of recursive sub- and supra systems and it will have a set of co-systems on the same level as itself. The time scales and transition rules between those systems may vary within wide limits. Hence, it must be possible to study even those effects within SAP.

2.7 Space

The space hypothesis (Holmberg, 1998) states that within a TC, let it be a region, a city, a nation, or the whole globe, current states or events at one point have a direct influence on future states at locations further away within the same space. In other words, there will be a global influence within the space or TC at hand. Lately the world has become even more interdependent and interconnected and that more people depend on more other people than ever before.

In an earlier work (Holmberg, 1998) I have implemented the space hypothesis in computer form as a Spatio Temporal Fuzzy Model (STF). Here, a global neighbourhood will be applied and the state variable is a continuous or fuzzy one. This will give a general transition function of the form expressed in equation 1.

$$s_{i,j,t+1} = f(s_{1,1,t} \dots\dots\dots\dots\dots s_{m,n,t}) \quad (1)$$

The global neighbourhood is stated in the right side of equation (1) because here all cells of the actual space, from the first $s_{1,1}$ to the last $s_{m,n}$, take part in the computing of new values. Further, the state variable s is continuous in the interval [0.0..1.0].

In conclusion, STF has been easily implemented at the same time as it has been robust and well behaving. Hence, it seems reasonable to adopt a similar scheme also in SAP.

2.8 Time

As has already been stressed above, the essence of anticipation is acting and even more, acting at the appropriate moment. This requires that the anticipating subject creates an overview of its entire life span. It has to mix its immediate sense impressions with abstract ideas and with memories of past events. Anticipation in this way becomes in a way a "flattening of time" (Van de Vijver, 2000).

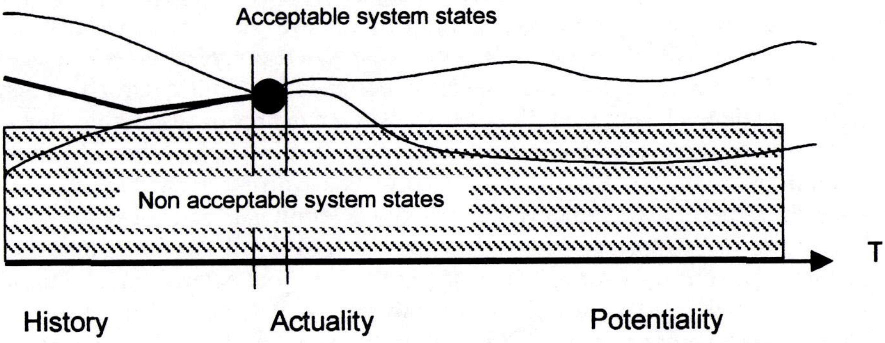

Fig. 6: The System Time-Space divided into three time intervals.

In an earlier paper (Holmberg, 2000) I have handled this through a weighted incursion procedure (WIP) with time divided into three intervals according to figure 6, i.e. History (H), Actuality (A), and Potentiality (P). First the new state, $s(t+1)$, is calculated individually for each interval. Finally, those three values are weighted together. In this way, three different new states, *sh, sa,* and *sp*, are obtained by calculation of historic data, actual data, and potential data respectively. The final result is obtained by weighting the three values together according to equation 2.

The weights w_h (history), w_a (actuality), and w_p (potentiality) mirrors the operator's attitude toward change and the passing of time according to Ackoff's (1981) taxonomy.

$$s = w_h \,.\, sh + w_a \,.\, sa + w_p \,.\, sp \tag{2}$$

with weights $w_h + w_a + w_p = 1.0$

Hence, a great w_h and with w_a and w_p close to 0 corresponds to a reactive attitude. Next, with w_a close to 1 and the other two close to 0 we have an inactive attitude toward planning and change. At last, the preactive attitude is displayed with w_p close to 1 and w_h and w_a close to 0.

None of those attitudes are especially good, according to Ackoff (1981), but may anyhow be feasible in certain situations. The recommended attitude, on the other hand, is a balanced mix of roughly equally great values.

The values $sh(t+1)$ are calculated by fitting a curve to the system's historical data and to extrapolate that function one step into the future. This is analogue to a recursive procedure and a fully deterministic system. However with $w_h < 1$ the final weighted value $s(t+1)$ will be just partly deterministic.

The actuality component $sa(t+1)$ is calculated from the partly known system rules or system interdependencies. One way of handling this situation is to use a modified STF-approach (Holmberg, 1998). Hence, instead of using the states of other geographical points the states of other system variables are used. In a way geographical distances are exchanged with logical distances and the new value of a system variable becomes a function of all the system variables according to equation 3.

$$si(t + 1) = f(s1(t), s2(t), \ldots sn(t)) \tag{3}$$

$$sp(t + 1) = (sc(t) + st) / 2 \tag{4}$$

For the $sp(t + 1)$ value, at last, the current state *(sc)*, the system target *(st)* and the equifinality state (*se*) are used in different combinations. For example, with the simple equation 4 the system will eventually converge toward its target or goal. This can be supposed to be the case when the system's resources are strong in comparison with the resources of its environment and co-systems. However, if the expected remaining lifetime of the system is short, it may be suitable to shift out *st* with the system's equifinality value (*se*). Hence, even if equation 4 may be too simple it shows the basic idea that the system's goal or target will have a great influence on its future states.

2.9 Energy

In TC all concrete processes are driven by energy. Odum (1994) has developed energy models suitable for expressing those relationships. Hence, it may be concluded that the amount of available energy puts a definite limit to what may be done within a region. Further, in terms of the quality of life index this implies a trade off between direct consumption of products and services and investments for the future in production plants, infra structure, and know-how. In SAP that distribution of energy may be handled according to the simplified equation 5.

$$E_{tot} = E_{c\text{-}ps} + E_{i\text{-}pro} + E_{i\text{-}struc} + E_{i\text{-}kh} + E_{ds} \tag{5}$$

E_{tot}	Total energy available during a time period
$E_{c\text{-}ps}$	Energy used for consumption of goods and services
$E_{i\text{-}pro}$	Investment in production plants and equipment
$E_{i\text{-}struc}$	Investment in infra-structure
$E_{i\text{-}kh}$	Investment in know-how
E_{ds}	Change in stored energy

2.10 Synthesis

This has been a fairly long discussion. Anyhow it has been necessary taking stock of relevant and usable knowledge and earlier research findings.

The result of this compilation can be summarised in a set of requirements as expressed in table 2.

That requirement set has in the next step to be used as an input to the forthcoming first preliminary design of the Soft Anticipatory Platform (SAP).

TABLE 2: Requirements on the Soft Anticipatory Platform (SAP)

1. The TC has to be handled as a complex socio-technical system on level eight in Bouldings's system taxonomy.
2. SAP has to support a systemic modelling relationship with ongoing learning.
3. The Anticipatory Loop (AL) has to be focused on acting.
4. It has to be a homeostatic system with embedded soft early warning based on multi-modality.
5. SAP models a system governed with both deterministic and normative laws.
6. SAP models a system, which is self organising (Autopoietic) with partly controllable and partly autonomous parts.
7. In SAP the TC is modelled and simulated with soft computing and a fuzzy logic approach.
8. SAP applies finalistic anticipation with decision making under uncertainty.
9. Space is handled according to the space hypothesis and the spatio temporal fuzzy model (STF).
10. SAP applies time handling with the weighted incursion procedure (WIP).
11. System processes are limited by available energy.

3 The SAP Test Area

In designing SAP, data from the Swedish Z region will be used as a reference frame and as an example. The Z region is a huge and sparely populated rural area with just one town and some minor communities. Water, used for electrical power production, and forests, used for timber and pulp production, but also tourism constitute the main economic activities. However, generally industry and economic life is weak and the population is aging and declining.

According to figure 7, the region may on a very general scale be divided into five main areas, mountain area, forest area, river area, town area, and surrounding environment. This last area is not really part of the Z region but it is not possible to treat Z as a closed system. Hence, the environment area serves as an "outside" system, i.e. an aggregate of everything outside of Z region. In many respects the surrounding area is stronger and better off than the Z-region

In its striving for a positive and sustainable development the county administration has applied a Resource and Environment Policy Plan (REPP) with four main categories,

- (1) resources,
- (2) resource claims,
- (3) restrictions and regulations, and
- (4) decisions and positions taken.

However, there are many other decision makers besides the county administration. The more powerful and influential ones, especially within forestry and hydro electrical production, are to a high degree located outside of the region, i.e. the situation may from a decision point of view be seen as a form of domestic colonialism.

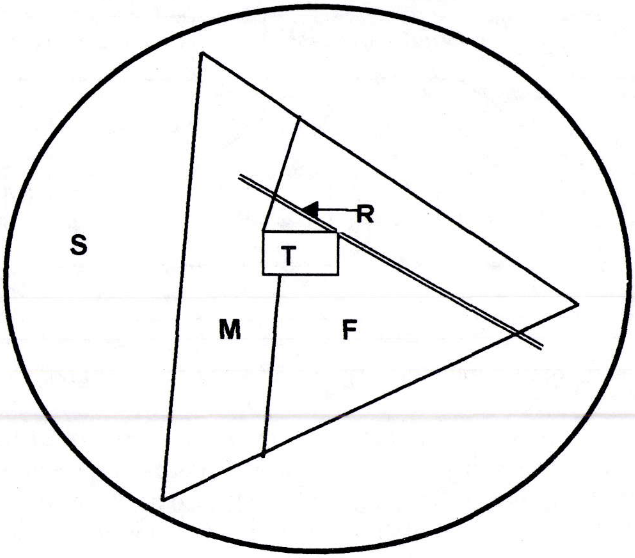

Fig. 7: Schematic map of the Z region with its surroundings (S), mountains (M), forests (F), river (R), and town (T).

4 The SAP Design

The preliminary design of the SAP is in condensed form given by the following points.

- The states of the territorial concern (TC) under study is represented by normalized fuzzy values, i.e. the state variables indicates to what degree the actual point or area belongs to the set of acceptable or good values. In other words, a value close to 1.0 says that the variable is well within its limits and a value close to 0.0 that it is far outside of those.
- During the whole simulation, state variables for a set of selected reference points (RP) are kept in a global state vector (SV).
- With a geographical distribution formula (GDF) the state values for an arbitrary point within the TC may be calculated.
- New states are calculated with a set of difference equations, each representing a process within the TC.
- The code for each simulated process is encapsulated in an individual procedure or method. The exact behaviour of those process procedures is controled by parameters.

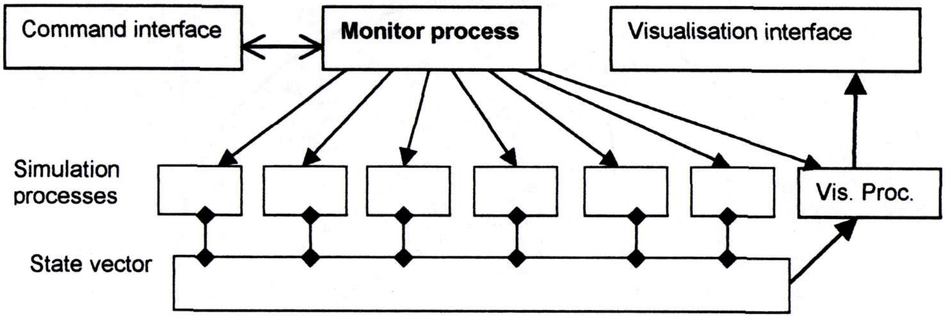

Fig. 8: General structure of SAP simulation program

- The processing of new states is according to figure 8 controlled by a monitoring procedure (MP). By small changes in that MP process procedures can easily be added or withdrawn. The path through those may also be changed.
- Each simulation step consists of four main phases according to figure 9. Phase 1 concerns decisions about creation or production of new values. This production decision is mainly about distribution of production resources but also about the geographical distribution of the production. In Phase 2 the results of the production are calculated. Decisions concerning distribution of the production results on different sectors and geographical areas are taken in phase 3. In Phase 4, at last, different anticipatory quality indicators are calculated. Before the next simulation step it is possible to go into an extra computer phase of reflection and learning. That learning may lead to changes in the computer program and its underlying model.

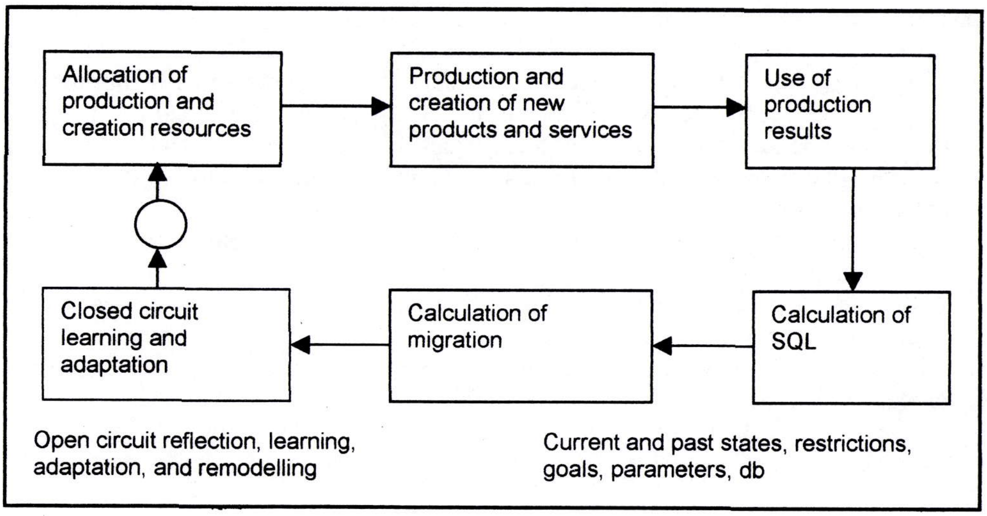

Fig. 9: Main working phases of SAP.

- SAP is implemented on a PC in a RAD environment. This makes it possible for the user to (re)model, simulate, anticipate, and reflect in a direct and interactive manner.
- In SAP relevance and simplicity are more important than realism and fitness to real data.
- SAP is preliminary a learning tool.
- Each process in SAP has its own periodicity. Hence all processes are not activated in each time step.

5 Conclusions

The work reported in this paper may be seen as the first step in a larger research project. Hence, some work has been accomplished while other things remain to be done. Anyhow, the project has already caused some new reflections.

5.1 Current Status of SAP

The necessary theoretical based is established and requirements are derived. At last, a first preliminary design of the Soft Anticipatory Platform (SAP) has been formulated. The next major step will hence be the implementation of SAP. With the SAP-tool up and running on a computer the envisaged learning according to the simulating, reflecting and acting model may start.

Such a learning loop may, for example, include testing of different development and maintenance strategies. Examples of test questions include:

- What is the best trade off between consumption and investment in infrastructure and know how?
- What is the best mix of investment in infrastructure, production equipment and research and development (know how)?
- What is the trade off between concentrating the population and other resources to one or a few places and to evenly distribute all resources over the whole surface?

5.2 Lessons and Reflections so far

Models and modelling approaches in urban and regional planning and design are numerous. However, the solution presented here may anyhow express some new features. Most important among those is the combination of two currently emerging new research areas. Those are anticipatory spatial modelling and computing, and soft computing applied on fuzzy decision support.

The potential of those approaches together with a great number of other relevant, but so far unexplored, research findings have turned out to be very strong. Hence, the objective of developing better means for handling complex and incomprehensible problem in geographical space seems possible to attain.

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