SDA:
System Dynamics Simulation of Inter Regional Risk Management Using a Multi-Layered Model with Delays and Anticipation

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Abstract-*Even in inter regional risk management phenomena of retardation and adaptation play an important role in the interplay between different logical management levels. In this paper it is demonstrated that an System Dynamics (SD) approach may be very suitable for modeling and simulating such phenomena. In some situations, however, SD approaches and modeling tools may pose some unnecessary restrictions on the procedure. Hence, the authors recommend a pragmatic and flexible attitude towards the choice of approach and tools.*

Key Words: *Anticipation, System Dynamics, Modeling, Simulation, Risk Management.*

1 INTRODUCTION

Anticipatory modeling has proved itself as a fruitful approach for simulating phenomena of delays and anticipation in management systems (Dubois and Holmberg, 2006a-b). Coming to handling of anticipation, however, Asproth et al (2001) have stated that solutions based on System Dynamics are "*nor effective nor convenient and straightforward*". The main draw-back being that in System Dynamic models everything is determined by the model's initial conditions. New system states are calculated exclusively with help of earlier ones. This procedure being quite contrary to an anticipatory approach. Nevertheless, Asproth et al (2001) have also found that System Dynamics modeling can provide a good understanding of the systems general behavior and properties. Finally they conclude that it may be necessary with further investigations of anticipation in System Dynamics models. Hence, the purpose of this paper is to clarify the possibilities of handling anticipation with help of System Dynamics.

2 RISK MANAGEMENT SYSTEMS

Schwaninger (2000; 2001) has provided a model of the logical levels of management in any organization. Figure 1 is a simplification of Schwaninger's model but anyhow it demon-strates the existence of complex relations and interdependencies between levels. Due to those relations decisions on one level may have surprising and unforeseen consequences on other ones (Dubois and Holmberg, 2006a). Further, the status of higher levels may be taken as an indicator or prediction of future status of lower levels. As a consequence, in taking decisions on a higher level it is necessary to anticipate desirable future states on lower ones. Seen from another perspective, any management system is a multi-level system with delays. It is those delays that are the great challenge to management. Anticipation is here the main method to handle those delays and to stabilize the system.

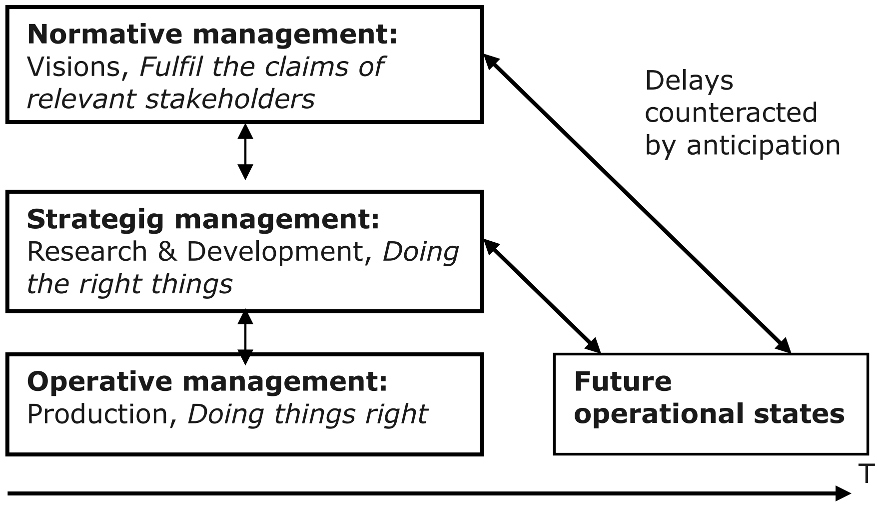


Figure 1, Management model with interdependencies between logical levels of organizational planning and decision making.

Let us take inter regional risk management as an example. Here, as outlined in figure 2, a geographical region is divided between two nations, each governed by its own organizational bodies. Those national bodies, however, tries to coordinate their actions in order to obtain synergistic effects and an optimized security level over the whole region.

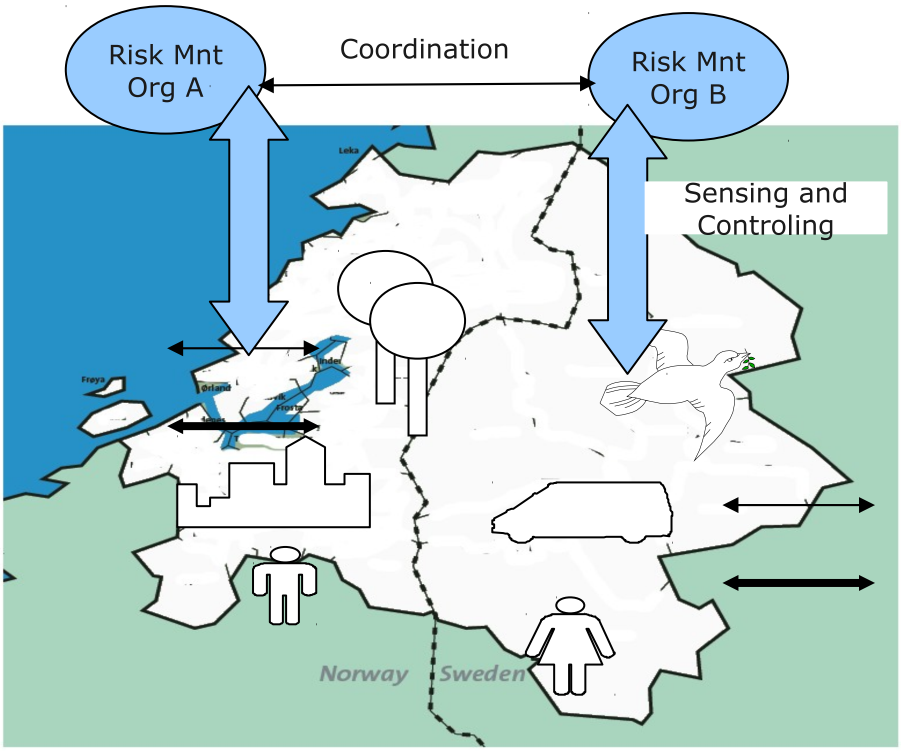


Figure 2, Region governed by two coordinating national risk management organizations.

In mapping the generic model according to the interregional case according to figure 2 the following couplings can be made:

- Normative management here stands for identification and admission of security stakeholders and their relevant security claims.
- Strategic management besides research and development, training and other preparations also stands for interregional coordination and communication with other management centers.
- Operational management in the interregional security context means command and control of concrete security operations.

For the simulation case the interdependencies between levels, which are shown in figure 3 are taken into account.

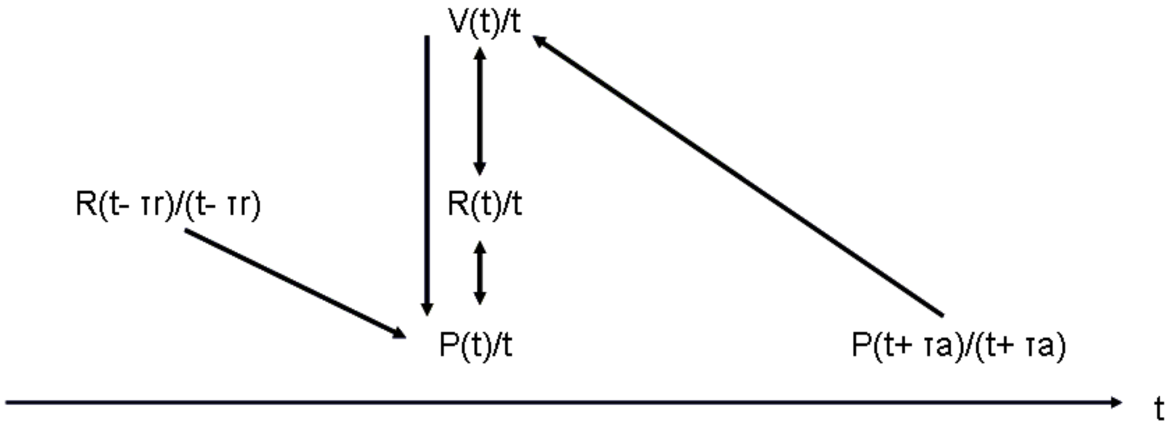


Figure 3, Considered interdependencies in the simulation models.

The normative level (V) is influencing the two lower ones. The strategic level (R) is influencing both its higher and lower level. Besides that, the strategic level from earlier time steps is influencing the current operational level (P). The operational level in its turn has an influence at the strategic one (R). A last influence goes from future operational levels back to the current normative level.

Of course this is a big simplification compared with the real situation. As will be seen in the forthcoming simulations, however, it is rich enough for providing good insights and learning opportunities.

3 ORIGINAL APPROACH WITH ANTICIPATORY MODELING

The original multi layered model with anticipation and retardation was developed by Dubois and Holmberg (2006b). It was not focusing specifically on security management. Instead it handled a general management case. The basic part of the model will be shortly recapitulated here.

3.1 From Model to Simulation Tool

The management situation expressed in figure 3 was initially represented with the following differential equation system (Dubois and Holmberg, 2006b).

$$dP(t)/dt = [cR(t) + eV(t) - d]P(t) \quad (1)$$

$$dR(t)/dt = [f + bV(t) - cP(t)]R(t) \quad (2)$$

$$dV(t)/dt = [a - bR(t) - eP(t)]V(t) \quad (3)$$

giving an explicit model at the current time t, with the set of parameters a, b, c, d, e, and f.

From that start in eqs. 1-3 a thorough mathematical analysis ended with a discretization schema as result. So, with the development until the first order of the anticipated production, the algorithm of this model with the Euler

schema is given by

eqs. 4-6.

$$P(t + \Delta t) = P(t) + \Delta t[cR(t - \tau R) + eV(t) - d]P(t) \quad (4)$$

$$R(t + \Delta t) = R(t) + \Delta t[f + (bV(t) - cP(t))R(t)] \quad (5)$$

$$V(t + \Delta t) = V(t) + \Delta t[a - bR(t) - e[P(t) + \tau A[P(t + \Delta t) - P(t)]/\Delta t]]V(t) \quad (6)$$

With this algorithm, the retarded term is computed explicitly without the Taylor development. It is to be pointed out that the Euler algorithm is numerically unstable. For example, a system with an orbital stability becomes unstable with the Euler schema (Dubois, 2001). But, with an incursive algorithm (Dubois, 2001), the orbital stability of a system is conserved. But this question will not be further discussed here.

Next a software tool implementing the model was designed and built. The purpose of the tool was to visualize the dynamics and to test the validity of the model. The computer tool, which we named Multi-Level Management Support Simulation Tool with Anticipation and Retardation (M2-STAR), was designed to meet the following criteria and requirements. Firstly, M2-STAR has to be reachable over the Internet so everyone with access to the net will be able to use and test the model. Secondly, M2-STAR has to be open source so everyone will be able to change and improve the model. And Thirdly, M2-STAR will be developed and run with free and commonly available development and run-time environments. According to those specifications, M2-STAR was implemented as a web-application based on an Apache web server and with PHP as programming milieu (Dubois and Holmberg, 2006a).

M2-STAR, in its first version, was built with the following algorithm:

$$P(t+1) = P(t)+dt[cP(t)R(t-tau)+eP(t)V(t)-dP(t)]$$

$$R(t + 1) = R(t) + dt[f + bR(t)V(t) - cR(t)P(t)]$$

$$V(t + 1) = V(t) + dt[aV(t) - bV(t)R(t) - eV(t)P(t)]$$

$$-e(ant)V(t)(P(t + 1) - P(t))$$

$$-[e(ant2)/2dt](V(t)(P(t + 1) - 2P(t) + P(t - 1))$$

with a second order Taylor anticipation ant and retardation tau.

3.2 Experimental Simulation Runs

By running the simulations with different parameter settings a great diversity of results were obtained (Dubois and Holmberg, 2006a). Here just a few glimpses of those results will be given. In simulation 2, for example, there is no connection between the levels. As a consequence, the research increases while production and vision decrease. Hence, we have a got a demonstration that the three levels may not work independently of each other. Contrary, they have to be carefully coordinated (Fig. 4).Figure 5 shows output from a run with great retardation while figure 6 shows the result of introducing an anticipation factor in the same retarded system.

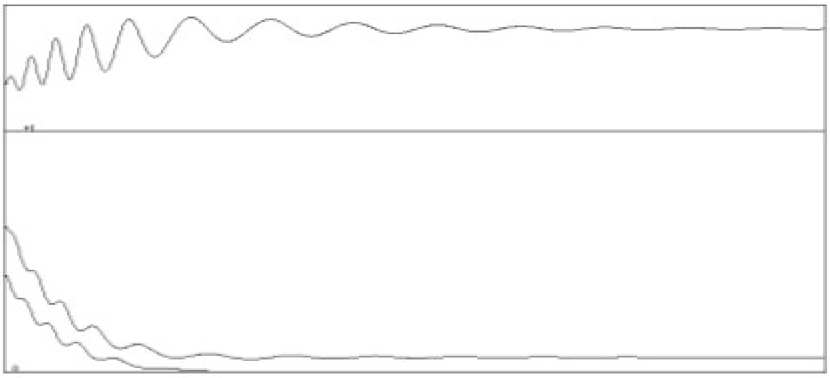


Figure 4. Simulation with no connection between the three logical levels.

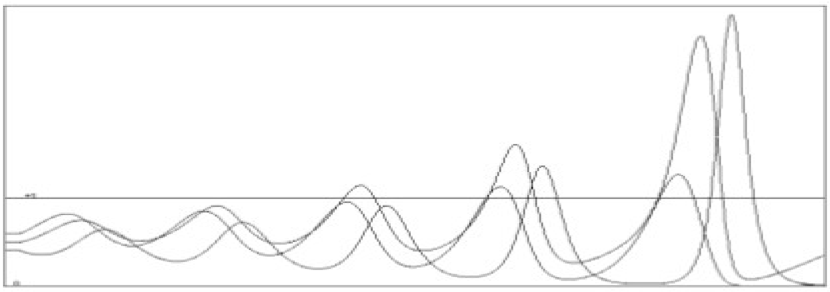


Figure 5. Simulation with great retardation.

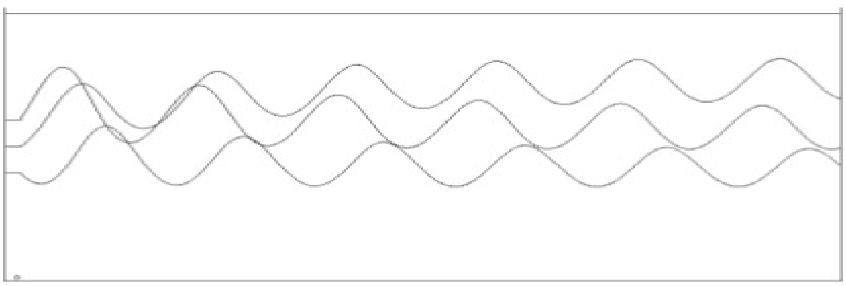


Figure 6. Simulation with both retardation and anticipation.

4 SYSTEM DYNAMICS APPROACH

System dynamics (SD) as developed by Forrester in the fifties (1961) has by now evolved into a well known methodology with wide application and with the most extensive implications (Forrester, 1994; Lane and Schwaninger, 2008; Schwaninger, 2011; Kljajic and Borstnar, 2011).

For our purpose here, however, we just have to focus on the core concepts of SD. The basic idea of SD modeling being based on the assumption that every system can be described by a set of interconnected Flows (Rates) and Storages (Levels) according to fig. 7. Here Fin and Fout are examples of flows in and out of the storage L. Further, there are influence arrows going to, i.e. impacting, Fin and Fout and an auxiliary control variable v. The clouds, at last, represent the system boundary, i.e. everything outside of the model or not being considered in it.

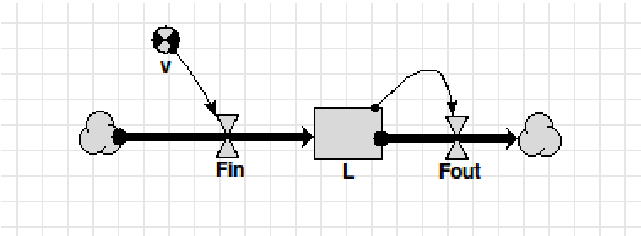


Figure 7. Core elements of System dynamics models.

For simulation purpose the dynamics of the model is translated into difference equations of the following generic type:

$$L(k+1) = L(k) + dt[Fin(k) - Fout(k)] \quad k = 0,1,2...,n$$

Here k represents discrete time and dt the time interval of computation. L is the level (system state) and F is the flow in and out. Initial values and values of Fin and Fout for each time step being calculated in auxiliary functions.

4.1 A First System Dynamics Model with Simile

There are many software packages for design and simulation of SD models around[1]. For this experiment we chose Simile[2] mostly of pragmatic reasons.

A first attempt to translate the interdependencies outlined in figure 3 into a SD model is shown in figure 8.

1 http://www.vensim.com/sdmail/sdsoft.html (2012-02-03)
2 http://www.simulistics.com/ (2012-02-03)

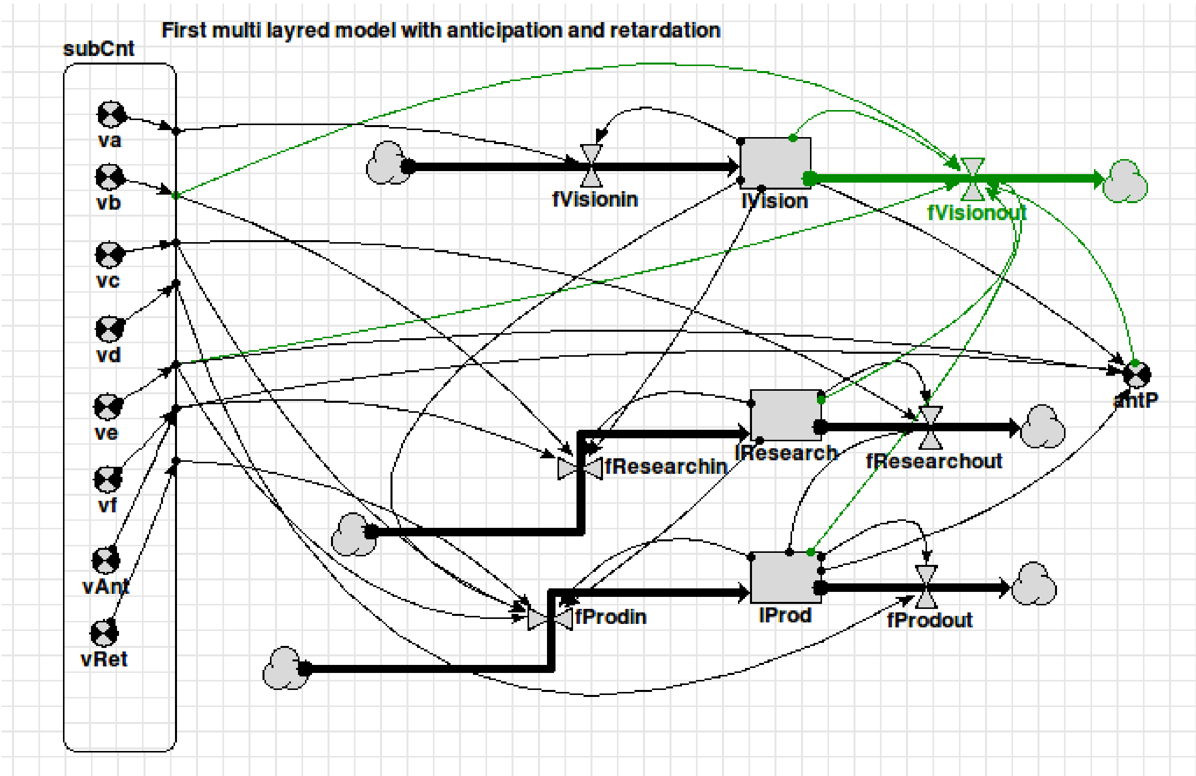
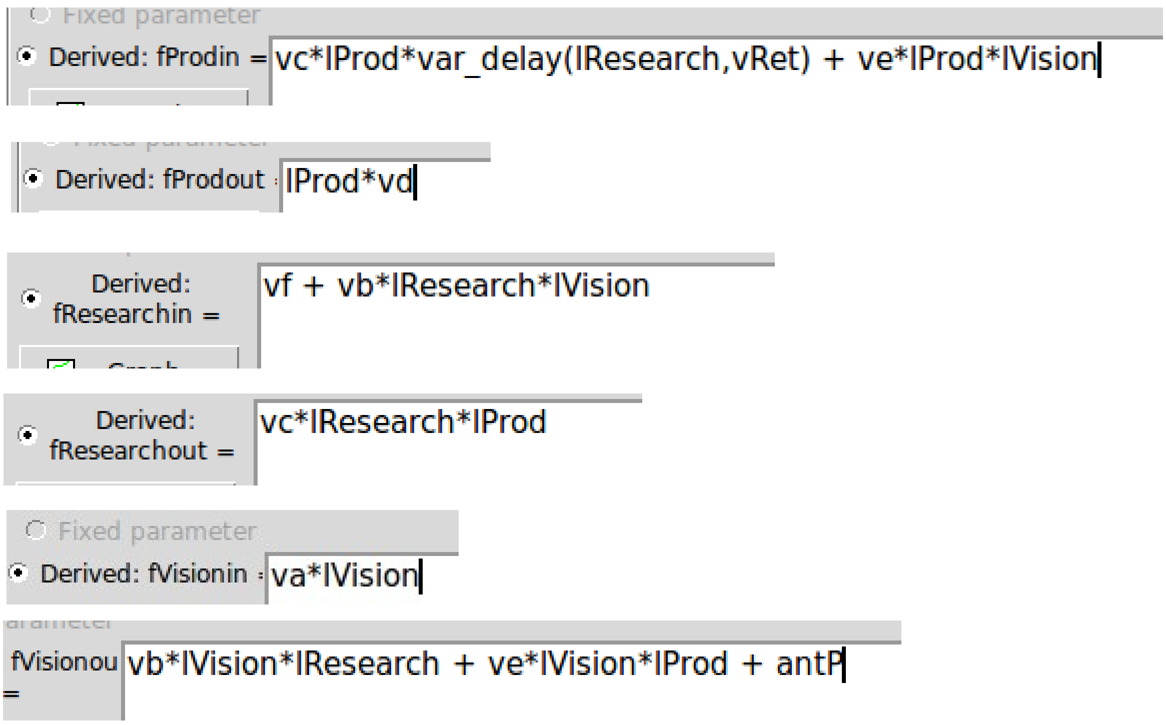


Figure 8. First SD model of the inter regional security system.

The flows in and out from the levels were defined in the following ways with the algorithms taken directly from the original model (Figure 9).



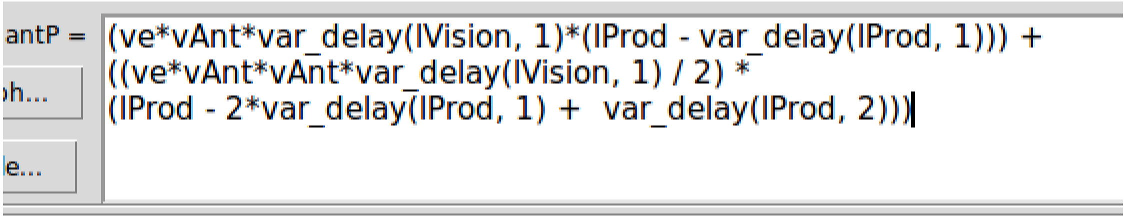


Figure 9. Definition of algorithms in the model.

Below follows the output from some simulation runs with this model and with different delays and anticipations (Figure 10-12).

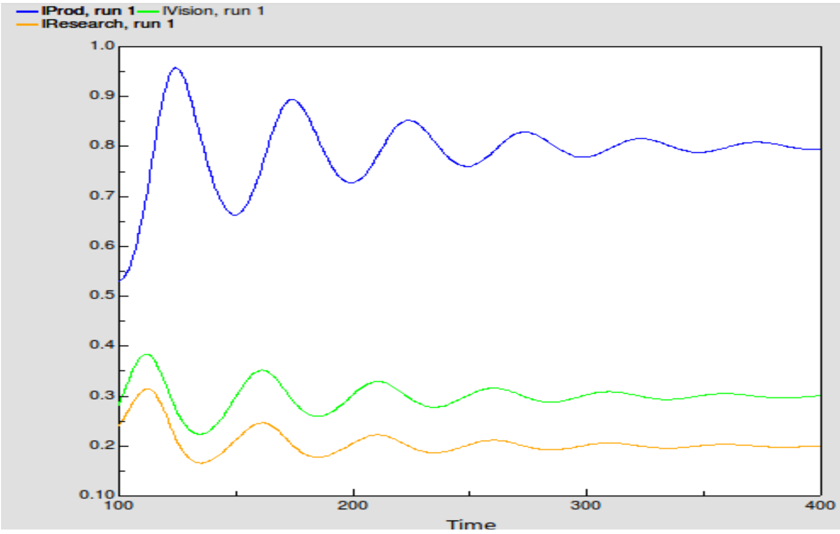


Figure 10. Run with delay = 0 and anticipation = 0.

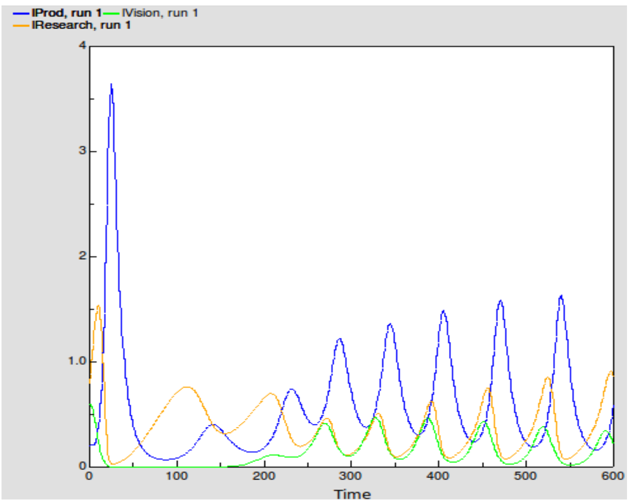


Figure 11. Run with delay 6 and anticipation 0.

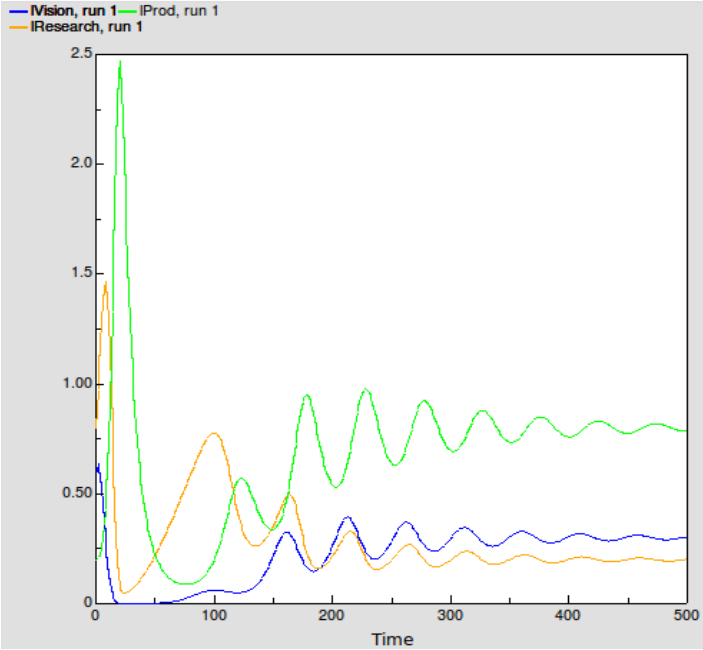


Figure 12. Run with delay = 4 and anticipation = 2.

In short, it turned out that the original model could be transformed into a SD one with a more or less identical behavior. The process was fast and straightforward. The SD-model, however, is in this form not fully adapted to the intended context of inter regional security management.

4.2 Possible Extensions

In the inter regional security context there are several security bodies active. Each of them can be modeled and simulated in the way discussed above. The real challenge, however, is to model the net result of their coordination and cooperation efforts. Here the sub model feature of the Simile tool comes in handy.

Another challenge is to introduce a coupling between risk estimations and an anticipatory approach into the model. By tradition rescue operations are based on a reactive paradigm. Hence, there is always some sort of alarm that will trig the rescue work to start. With an anticipatory approach, on the other hand, risk estimates could be used to start at least preparatory rescue operations. In this way delays could be offset and considerable time could be gained. So, having access to a model with anticipatory behavior would ease an upcoming discussion concerning a possible shift toward an anticipatory paradigm with the responsible security officers.

5 COMPARISON AND ASSESSMENT

From one point of view the most important contribution of this paper may be the introduction of a multi-layered management model with retardation and anticipation into the application area of inter regional security and crisis handling. On the other hand a large part of the paper has been about translating an ad simulation model into one implemented with System Dynamics (SD) methods and tools.

So in comparing the two approaches we have found the following:

- It is fast and straightforward to get the SD simulation model up and running. So here the claims of the providers of SD-tools have been supported.
- The main model structure is well visualized in the graphical model display while the most important properties of the model are hided in the algorithms (formulas).
- With the easiness to start modeling with the SD-tool it may be tempting to jump the rigorous mathematical analysis underlaying the model. That may have a negative impact on the final result.
- By using a known methodology and established tools there are also a given audience or receivers of your work. Communication of results will with other words be facilitated. On the other hand, when addressing a group of user within a specific application area they probably have never heard about whatever modeling methodology.
- Using a proprietary tool will always have as consequence that you become “locked in”. Here Internet and open source tools have a clear advantage.
- As a general rule: Basic tools provide the greatest freedom but are also more cumbersome. Specialized tools are more fast and straightforward to use but also more restricted.
- Based on this assessment we will not make a definite choice. We will be free to select specialized tools for some tasks and basic ones for others.

6 CONCLUSIONS

In this paper we have demonstrated that the generic multi layered management model with delay and retardation is also applicable on inter regional risk management. Further, it is straightforward and reasonable easy to use System Dynamics (SD) methodology and tools for conceptualizing and implementing a simulation model of such a management system. There is also a potential in the SD approach for digging deeper into questions around retardation and anticipation in inter regional risk management. There are, however, situations there a SD approach may impose unnecessary restrictions on the work. For that reason we would argue for a pragmatic and flexible attitude when coming to the choice of methodology and tools.

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