Analysis of a serious accident emergency drill with a simulation model

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ABSTRACT

Studies of labor risks with simulation models can be categorized into two groups: those which analyze serious accidents to obtain applicable rules for the future, and those which analyze the rules and mechanisms of control of risks to simulate their functioning before potential accidents occur in order to identify and manage the necessary guidelines of prevention and course of action. Here we have a) an ex-post approach where we study the chain of events that have caused the accident to prevent it from repeating itself, and on the other hand we have b) an ex-ante approach that analyzes the complexity of the relations between the parts of the system that can give rise to accidents and simulate diverse strategies that enable reduction of the risk. Later the system of prevention of labor risks of a generic company is described using a causal graph, and that same graph transforms itself in a model of simulation - in spite of handling qualitative variables - to simulate the effects that are produced in a serious emergency exercise.

***Keywords**: risk; labor; accident; safety; emergency; control; prevention; simulation model; system dynamics; causal loop diagram*

Simulation models have shown a high level of effectiveness in specific activities in companies, such as, for example, the design of mechanical components, where it is possible to carry out trials of vibration resistance in a simulated model before a prototype is built. Simulation models are also useful in production management because they allow foreseeing the impact of sudden changes on demand levels or a shortage in the stock of one of the main resources, thus allowing for forward-planning of effective solutions for each situation.

Inside a company it is also possible to use Dynamic Systems simulation models in the realm of management (Sterman, 2000), and a extensive bibliography with abundant examples that can serve as an orientation is available. Thus, before using this technique in our own situation we can check what others have done while tackling a problem similar to ours.

System Dynamics is a well-defined methodology with the first publications dating from more than 50 years ago, and a sizable number of projects and publications that capture the experiences of researchers and professionals who have used the simulation models created with this methodology to analyze a wide spectrum of areas and problems.

In the business field we can differentiate between models that deal with production issues and those related to managerial ones. Management-focused simulation models have an interesting distinguishing factor that is not commonly found in other methodologies and that is the need to explain them in a clear and fast manner to people not familiar with the methodology in order to justify conclusions or suggestions in a convincing way. It is indeed a formidable challenge, which sometimes is not achieved and hurts the development of otherwise valuable projects because the decision-making managers may not have enough time to go deeply into the details or hypotheses used to inform the design of the simulation model.

It is necessary to design a detailed simulation model so as to analyze the problem and being able to justify suggestions or conclusions. Even further, it is necessary to design a very simplified version of such model so we can explain it in a clear and concise way how the conclusions are not derived from personal opinions but from the rigorous evaluation of different alternatives. This situation is not present in other simulation models in companies, like production management, where the person responsible for it will need to know the model structure in detail, what values were chosen, where the data came from, what simulations justify the suggestions and where he even may be concerned with ease of use and the option for further updating of the model.

This work illustrates with an example the complete process of using simulation models with System Dynamics in a specific managerial topic, in this case labor accidents prevention, paying special attention to the need for presenting the management team with clear conclusions based on a simple simulated model. The process starts with the precise definition of the problem (labor accident risks), followed by displaying the expert's opinion in a causal diagram, which will later be translated into a simulation model. The model's variables will then be assigned values, thus allowing for their observation over time allowing us to reach convincing conclusions or recommendations. It should be noted that sometimes the causal diagram itself offers enough information about the structure of a problem to allow for solid conclusions (Senge, 1990, Kim, 1992, Marais, 2006).

In the field of labor security or labor risk prevention there is a recent paper (Miang, 2010) with a general review and a selection of the most important contributions. Many of the published works analyze accidents that have already occurred and thus deal with particular details of those incidents. For our purpose, (which is to illustrate how to offer good recommendations based in a simple simulation model) we have selected an interesting work (Cooke, 2006) that offers a generic vision of risk and labor accidents based on the opinions of subject matter experts. Nevertheless, it would be very difficult to present this work in a few minutes, since the simulation model is quite complex and has close to 40 variables. We will use these subject matter experts' concepts and opinions found in Cooke's paper as the basis for building a case that illustrates the whole process of applying System Dynamics simulation models to the field of management.

1. CASE DESCRIPTION

A transport company involved in moving dangerous goods has never had any serious accidents, even though it has had many small ones. They want to analyze the effects of carrying out a serious work accident exercise before taking it to actual practice because of the high cost attached to it.

On the basis of several meetings with managers and employees of the company, a causal graph is first developed, gathering the elements that intervene and the relations that exist between them.

Before constructing and executing the simulation model it is useful to draw the behavior we expect (figure 1) of the principal variables of the system before and after the moment the serious work accident exercise takes place (in month 6). Later we will compare our intuitive expectations with the results of the simulation model in order to analyze the reasons for the difference between expectations and results.

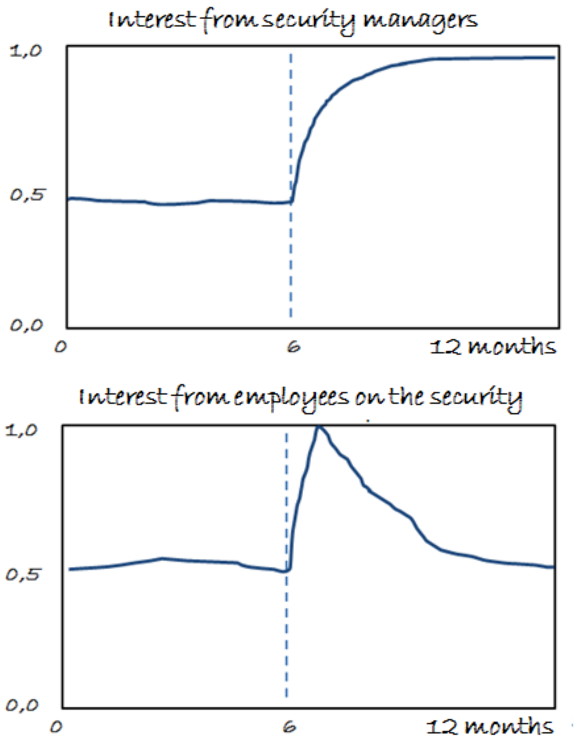

Figure 1

The experts think that after the safety exercise (in the 6th month), interest in safety topics will increase on the part of the managers and executives of the company. Furthermore, it is also going to increase the interest in safety on the part of the employees, but only for some time. As a result the level of risk of accidents will decrease for a specific period of time, returning slowly to the current level of risk.

2. CAUSAL LOOP DIAGRAM

A causal loop diagram is an important tool used in the initial stages of a system analysis which qualitatively and explicitly expresses our ideas about the basic causal feedback relationships – their linkages and whether positive (increasing an effect) or negative (decreasing an effect) - between major, key components of the system under study. In this example, (figure 2) a major increase in interest in safety topics by the managers prompts an increase in resources dedicated to safety (for example improvements in systems maintenance, active safety policies, risk analysis, etc.), that thereby – causally - diminishes the risk of accidents.

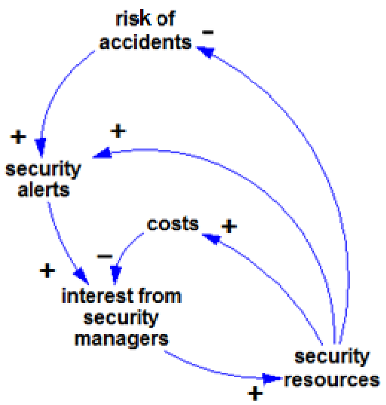

Figure 2

In addition, dedication of more resources to safety increases general safety awareness because there are more measurements of all kinds (i.e,"positive feedback loop"). This increase in safety awareness leads to an increase in the interest of managers in safety. On the other hand, we need to remember that as more resources are dedicated to safety, we incur higher costs, acting as brake or stabilizer (i.e, "negative feedback loop"), diminishing the interest of managers in safety. In addition to effects on management, a key element in considering safety topics are the employees themselves who experience the risk directly. In this way (figure 3) a major risk of accidents is translated into more reported minor accidents by the employees. Subsequently, a large increase in the number of minor accidents increases the employees' interest in safety topics, increasing their knowledge of the topic and therefore, on the basis of the information or the experience, diminishing the risk of accidents. Representing these elements and relationships with a causal graph, we are able to observe that there exists a link of a negative sign, stabilizing the system. This way, an increase of risk provokes an increase of accidents, which motivates the employees to improve their knowledge, which in turn diminishes the risk.

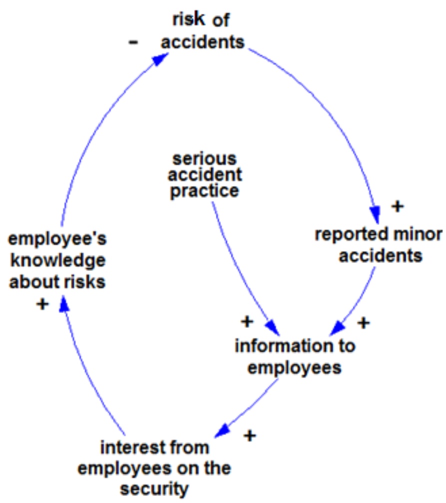

Figure 3

Do bear in mind this additional point relating to the employees: they have to report and communicate information about accidents, especially the minor ones. In this way, (figure 4) an increase in reported minor accidents makes it necessary for management to allocate some additional resources in order to investigate the causes of each accident, to evaluate its importance, to propose preventive measures, etc.

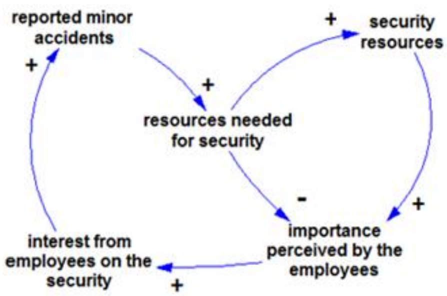

Figure 4

A greater need of resources dedicated to safety translates into having more resources allocated, which, in turn, sends a message to the employees on the importance that the company gives to safety topics. Nevertheless the employees are going to perceive the importance of safety topics only if the resources dedicated to safety topics are equal to or more than those which are considered necessary. For this reason there is a link with a the negative sign, which indicates that" a greater need of resources produces a perception in the employees of a lesser importance in any measure that does not devote an equal quantity of resources in safety.

We can integrate the elements and relationships we have described above into one causal graph, such as the one that appears below (figure 5). Most of the elements are qualitative variables, to which there is assigned the initial value of 0.5 to gather the current situation. We are going to use this model to run a simulation throughout 12 months and to reproduce an exercise of serious work accidents in the 6th period in which this variable will take the value 1.

3. MODEL STRUCTURE

The causal graph of the model is formed by twelve elements and the relationships between them. All the equations are simple arithmetical expressions, without delays of information and linear relations, which will allow us to easily understand and explain the inner working and the results.

In general all the variables of the model have arithmetical simple equations that allow and support the initial values (0.5) throughout the time.

To simulate the accident it uses the function PULSE that is activated in the 6th period. To prevent the level of risk of accidents becoming zero or negative in any moment, the model uses the function IF THEN ELSE so if the risk is less than 0.2 and the impact of the knowledge and the resources dedicated to safety tend to make it go down and down, the variation is null.

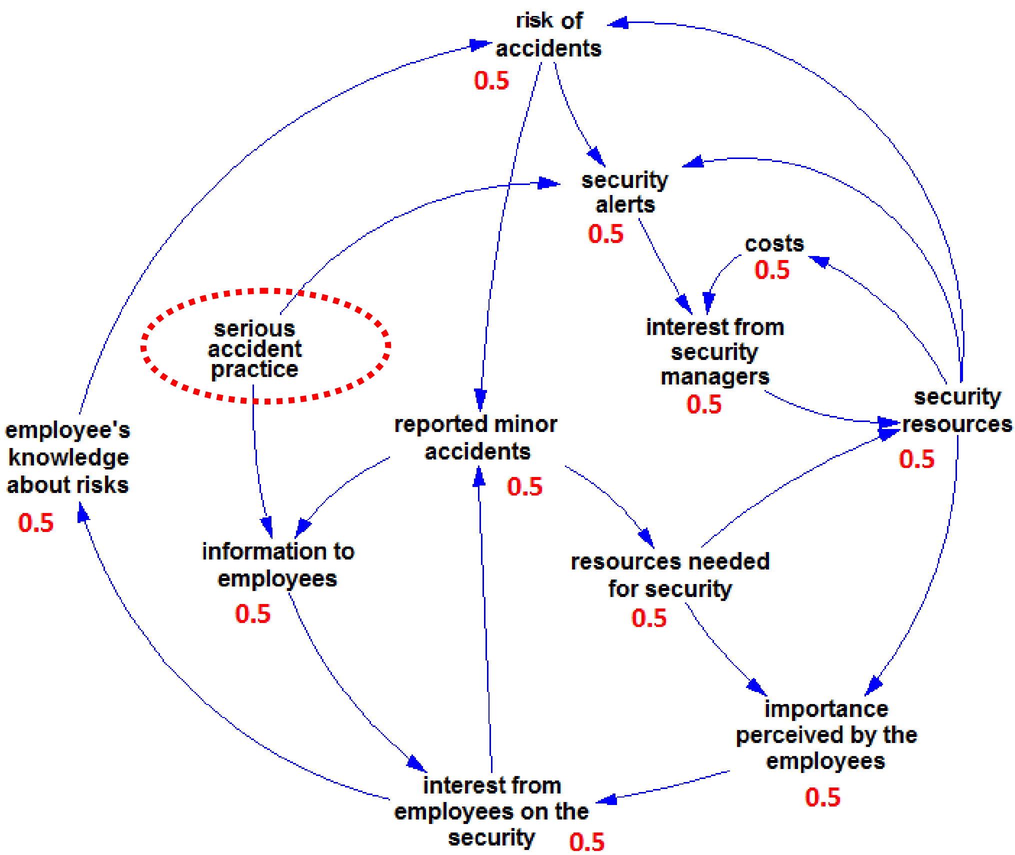

Figure 5

4. RESULTS OF THE MODEL

The model enables the analysis of the reasons for the changes that are perceived in the variables after the exercise of a serious work accident. In particular, it shows that the number of reported non-serious accidents increases and why the safety alerts diminish.

The number of reported non-serious accidents increases after the exercise. This happens because the interest of the employees in safety topics increases, and they are much more careful before any accident occurs - even if the accident would be negligible. This is in spite of the fact that the risk has diminished because after the exercise the resources allocated for safety have increased. It can be seen the behavior of these variables in figure number 6, where the risk (A) diminishes because of major resources in safety, but the interest of the employees in safety (B) increases due to the major information about labor risks..

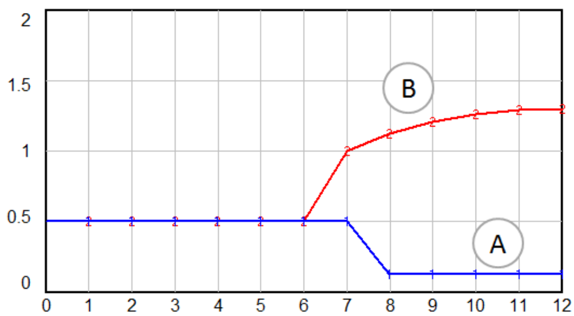

Figure 6

We see that the number of reported minor accidents increases is linked to the increased information about labor risks that the employees receive and their increased interest in safety topics, which translates to better knowledge of the risks, and thereby a reduction in the level of risk.

The safety alerts diminish after the work accident exercise (figure 7) basically due to the fact that the risk (A) diminishes. This occurs as a consequence of the significant safety resources that are allocated to safety topics (B), or because of better organization and efficient use of the resources, on the basis of the conclusions that the experts obtain in carrying-out the exercise.

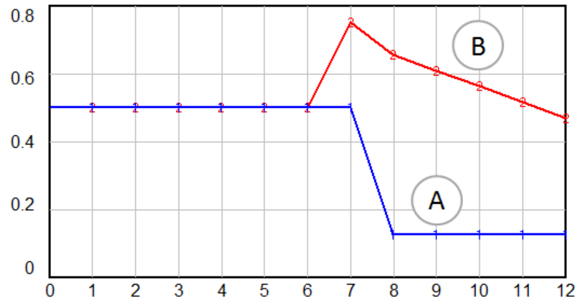

Figure 7

The interest of the managers in safety (A) has a similar behavior (figure 8) to the risk perceived by them across the safety alerts (C). Thus, it has a maximum value coinciding with the completion of the serious work accident exercise, and later it diminishes to lower values than the initial one.

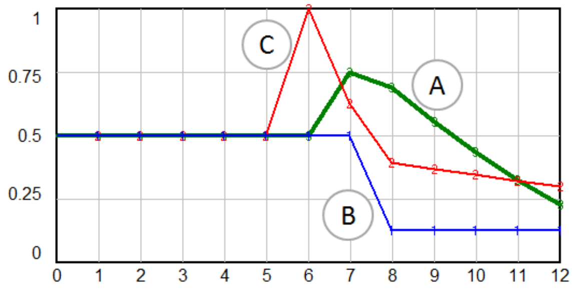

Figure 8

Nevertheless (figure 9) the interest in safety topics of the employees (A) is remains elevated after the exercise and we can even observe that it is increasing progressively. This slightly intuitive behavior owes to the different dynamics of these variables as we will see later.

The interest of the employees depends on the information that they receive from the accidents they report. A serious isolated accident increases the employees' level of information, which increases their interest for safety (A), and this increases the number of minor informed accidents (B), which increases the quantity of information that they receive (C) in a loop.

This process only diminishes because of the negative behavior of the parameter reflecting the declining importance perceived by the employees, and that is because the resources allocated to safety are not the necessary ones in the measure that the interest of the managers is diminishing.

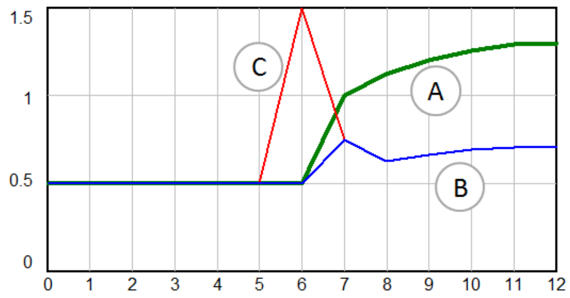

Figure 9

In this point, even though it is a theoretical exercise, it is important to compare (figure 10) the previous expectations of the company's safety experts (A) with the results that the model shows (B).

Sometimes the models confirm the previous expectations, but in complex systems counterintuitive behaviors often take place, so the model shows a different behavior from what was previously expected. In this case, after checking that the functionality of the model is correct, we can follow the model step by step from where the behavior of the model is has originated and compare it with the expectations in order to achieve a deeper understanding of the reality.

It is always possible to closely analyze the results of the model because the hypotheses used are those contributed by the actual experts. Therefore, the experts who have taken part in its design will not see the model simply as a black box.

This model is an example of the power that the causal graphs and the models of simulation of system dynamics have to analyze the dynamics related to labor risks, prevention of accidents, constant improvements in safety culture, safety costs analysis, etc.

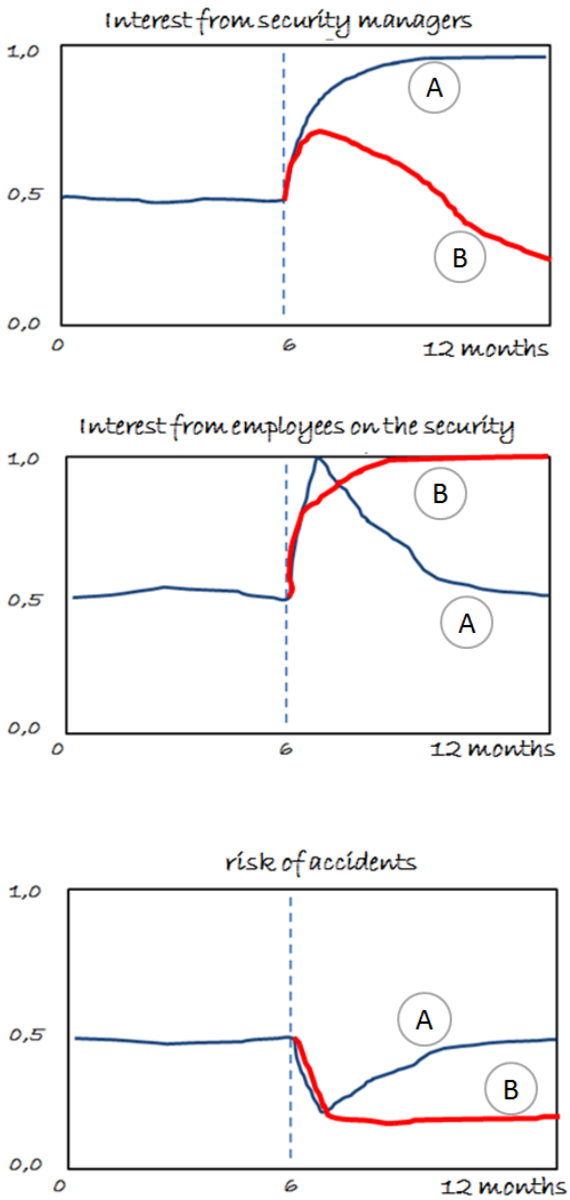

Figure 10

5. CONCLUSIONS

The simulation model elaborated by the experts enables us to observe that after a safety exercise of a serious work accident risk will decrease about 50% during a long time after the work accident exercise. Additionally the model allows us to observe (figure 11) how after a security exercise the interest of the managers (A) will diminish because they perceive a minor risk as a consequence of the existing additional measures of safety, meanwhile the employees are going to increase their interest in safety topics largely (B) due to the feedback loop across the information that they receive about minor accidents.

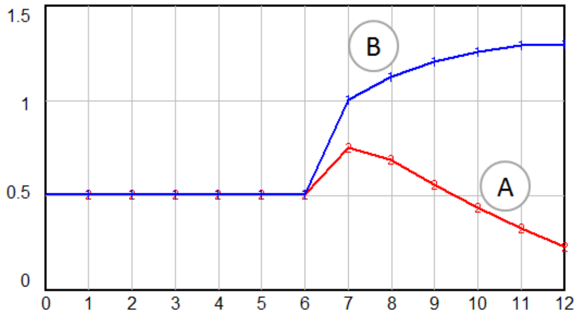

Figure 11

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6. MODEL EQUATIONS

(01) costs=security resources
(02) employees knowledge about risks= interest of the employees on the security
(03) importance perceived by the employees= 0.5+(-resources needed for security+security resources)
(04) information to employees=serious accident practice+reported minor accidents
(05) interest from security managers= INTEG (var interest managers, initial value=0.5
(06) interest of the employees on the security= INTEG (var interest employees, initial value=0.5)
(07) reported minor accidents= (risk of accidents +interest of the employees on the security)/2
(08) resources needed for security=reported minor accidents
(09) risk of accidents= INTEG (-var risk, initial value=0.5
(10) security alerts=(security resources+serious accident practice+risk of accidents)/2
(11) security resources=(resources needed for security +interest from security managers)/2
(12) serious accident practice= PULSE(6, 1)
(13) var interest employees= (information to employees +importance perceived by the employees)/2-0.5
(14) var interest managers=(security alerts-costs)/2

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