The Importance Of Time Dependence In Functional Modeling

A Case Study Comparing Modeling Methods for an Agricultural Process Application

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Abstract

Several methods of modeling systems are common in TRIZ for problem solving, system simplification, and improvement. Subject – Action– Object models are based on specific physical components of a system and the explicit effects they exert on other components of the system, and are derived from the Su-field modeling method of classical TRIZ. "Operational" models, generally known as "problem formulator" models, allow broader definition of a system's elements to include actions as well as components. Both models focus on whether those elements ultimately contribute useful or harmful effects to the primary purpose of the system or to elements supporting that purpose.

There is no direct way of using these models to deal with time-variable elements in the system model, or to deal with different aspects of a problem that occur at different levels of the system. Most TRIZ teachers emphasize the need to clearly identify the problems at each level of the system, and to solve them separately.

Causal loop models are useful in TRIZ to identify the system elements and actions in a system that are most pertinent to causing a desired change in performance, and add a powerful ability to understand the time dependence of conflicts. Organizing the views of the problem in a hierarchy of macro-performance, trends and patterns, accumulation of discrete results, and discrete events also clarifies the situation and makes the solution space more accessible.

A Canadian agricultural problem will be used to illustrate these issues. Flax straw from plants grown to produce seeds for oil is extremely tough material. Deciding whether to burn the straw, sell it for use as fiber or in wood-substitute products, or use it to feed cattle requires that farmers make many time-dependent and condition-dependent decisions to survive in the highly variable economic and physical environment in which they function.

1. INTRODUCTION

All TRIZ processes include a stage usually called "analysis of the zones of conflict," which emphasizes understanding the situation in detail in time, space, and circumstances. Altshuller made it clear that TRIZ analysis must reflect the nature of the real world:

"Complicated? Yes, indeed. The world in which we live is constructed in a complicated way. And if we want to learn about it and transform it, our thinking must reflect this world correctly. The complex, dynamic, dialectically developing world should find in our consciousness its full model which is complex, dynamic, and dialectically developing." (1)

1.1 Functional analysis modeling

In the first paper of this series, we examined the use of various functional analysis and modeling techniques (2), and found that the techniques which model the time dependence of a situation gave more useful suggestions for solving the problem than the static, or time-independent models. The time graphs in the Product Analysis module of Invention Machine's TechOptimizer™, D. Mann's essay on functional analysis (3, 4), and P. Apte and D. Mann's work on non-linear problems (5) all suggest a growing awareness of the importance of time-dependence in modeling a system, before applying any of the TRIZ methods to solving the system's problems. Likewise, the popularity of A. Seredinski's (6) and D. Mann's (3) system operator work show the awareness of the need to look at a problem from the perspective of time sequence and the magnitude of time intervals for complete understanding of the system.

1.2 Time dependent functional analysis modeling

Experienced TRIZ practioners have always done time-dependent real world system modeling as part of the preliminary analysis of a situation, but they have not created tools for TRIZ beginners to use to develop these insights. Rantanen and Domb (7) introduce the metaphor of Scylla and Charybdis from classical mythology to emphasize that a problem may have radically different nature at different times—Odysseus had different problems before, during, and after sailing between the monster and the whirlpool.

Only the highest level of ideal solution will resolve problems from all the time zones simultaneously. *The ideal system doesn't exist, but performs all its functions.* Neglecting to model the time relationships will lead to sub-optimum, sub-ideal solutions that may only perform some of the functions, in some of the time zones. Experiments with time-dependent causal loop models (8, 9, 10, 11, 12) demonstrate that a hierarchy of levels of analysis of a system under study will make the TRIZ problem solving opportunities much clearer.

1.3 Agricultural case study: Management of Flax Straw.

In order to explore these modeling systems with a real case study, the problem of flax straw in Saskatchewan Canada was selected. Agricultural systems are complex, time dependent, and subject to variation outside the control of the operator (weather, world market prices, investment in processing facility), but they are fairly easy to explain to audiences with a wide variety of technical knowledge and experience, as demonstrated in earlier work on functional analysis models using the no-till farming method (2).

2. DESCRIPTION OF THE FLAX CASE: Flax Harvesting and Residual Straw Disposal

Flax (*Linum usitatissimum*) straw from plants grown to produce seeds for oil is an extremely tough and durable agricultural by-product. After harvesting, the straw is accumulated and burned to clear fields. This requires human labor, equipment and fuel and may cause significant pollution.

L. usitatissimum grown for oil is a short (1 - 2 feet) multi-headed plant. Crops are rotated, as part of disease prevention, on a (minimum) four year cycle. There is some minor production of special papers and specialty fibers from the fibers of oil flax plants. In other regions, cultivars *of L. usitatissimum* are grown as tall (3 - 4 feet) single headed plants for fiber to produce fabrics such as linen. See Figure 1.

Figure 1: Picture of Flax oilseed plants, seeds, stems. Note extensive fibers at the cut.

Flax stems do not degrade; they last for years. Plant segments may carry disease and / or pests from year to year if left in place. Plant stems are too tough to be cut / chopped in the normally available grain combine equipment. Stalks can be cut / chopped after combining, but no other similar need / usage is observed on the farms; hence no multi-purpose equipment is routinely available.

The problem occurs through economic choice: It is cheaper (or at least more traditional), to spend the time and resources to pile or row the stalks and burn them in the field than it is to find alternate uses for the stalks as a product (13). See Figure 2. Processing the straw into substitutes for wood products and using it for cattle feed have emerged as alternatives in the last few years. See Figures 3a and 3b. These efforts to promote the use and added value processing of flax straw have recently become more organized in Saskatchewan (14).

Figure 2: Picture of rowed up flax straw ready for burning, and burning

Figure 3a: Picture of straw bales waiting for processing outside processing plant

Figure 3b: Picture of straw bales waiting for processing and plant for processing

3. MODELS FOR THE FLAX CASE

3.1 Function analysis

Subject – Action– Object models are based on specific physical components of a system and the explicit effects they exert on other components of the system, and are derived from the Su-field modeling method of classical TRIZ (15, 1, 2). "Operational" models, generally known as "problem formulator" models, allow broader definition of a system's elements to include actions as well as components. Both models focus on whether those elements ultimately contribute useful or harmful effects to the primary purpose of the system or to elements supporting that purpose.

3.1.1 The Operational Model

The operational model ("problem formulator") for flax farming is shown in Figure 4. This method is described in Ref. 16 and has been popularized by Ideation International's Ideation Workbench™ software. Each box represents either a useful or harmful function, and the arrows between boxes show relationships; that is, one function can cause or prevent another. A large number of potential problem statements are generated from this model by substitution in general formulas such as the following:

- Find a way to enhance the useful effect
- Find a way to remove, reduce, or prevent a harmful effect without losing the useful effect that is generated by the same process.
- Find an alternate way to create a useful effect
- Etc.

The TRIZ practioner has to examine the list of potential problem statements, select the ones that are most appropriate for the situation, and then re-express them in terms of the language of the situation in order to begin solving the problem. A sample of these problem statements is shown in figure 5.

The formulator model is typically created at a single instant in time. Additional diagrams are created for different time intervals, if necessary. This leads to development of problem statements that are not explicitly time dependent. This may make them superficially easier to solve, but it may not reflect the reality of the system. Note that this modeling system is not really intended to show multiple alternates. Alternates were forced in this diagram.

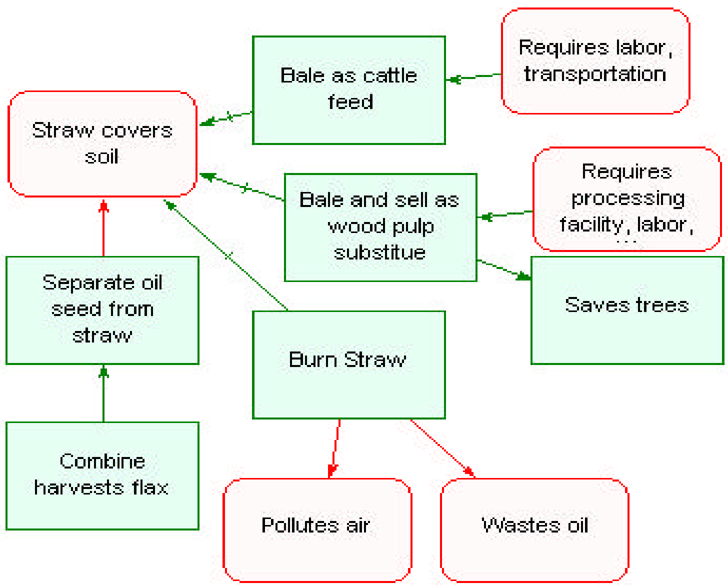

Figure 4: The formulator model for flax farming.

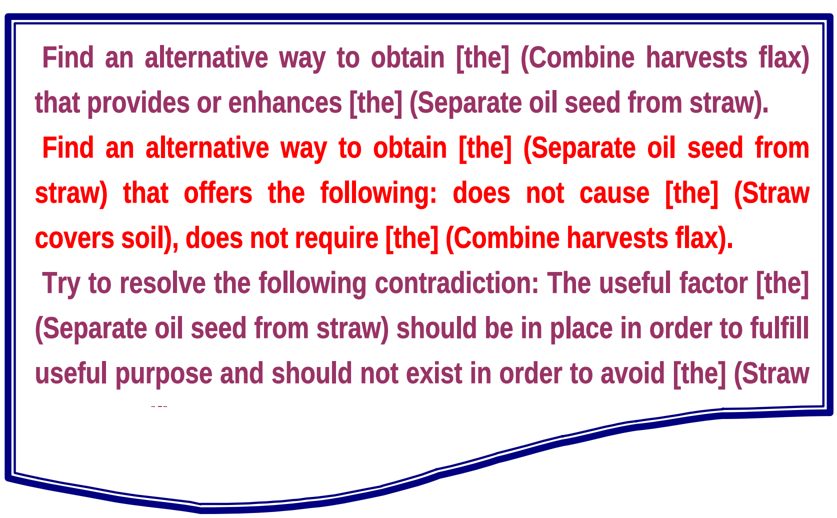

Figure 5. A partial list of the problem statements generated by the problem formulator, from the diagram in Figure 4. The full list has 14 problem statements, many of which can be expanded into 4-6 subsidiary problem statements.

3.1.2 Functional Model (Subject-Action-Object Model)

The function analysis model is based on system engineering methods of defining a function in terms of two objects and the action that one performs on the other. The graphical form of function analysis has been popularized in TRIZ through Invention Machine Co.'s TechOptimizer™ and Creax's CreaTRIZ™ as shown in Fig. 6. Solid arrows indicate useful functions, dashed arrows indicate useful functions that are not operating at their best value (either too much or too little) and wavy arrows or red arrows indicate harmful functions. Problem statements are developed directly from the graphics by examination, for example:

- Eliminate harmful functions
- Improve inadequate functions
- Find an alternate way to do beneficial functions.

Problem statements are also developed through the process of trimming, such as

- Delete functions. How can the useful function be performed without another function? Or can the result be achieved without the function?
- Delete components. How can the function be transferred to other components? Or can it be transferred to resources of the system?

Finally, in TechOptimizer, solution statements are developed by applying a list of generic problem statements, based on the 76 standard solutions (17) to the function statement. (For a function "A does X to B" there will be a family of statements such as "You may improve the action X by putting something between A and B" or "You may eliminate the action X by vibrating B" etc.) The solution to the problem requires re-formulating these solution statements for the particular conditions of the problem.

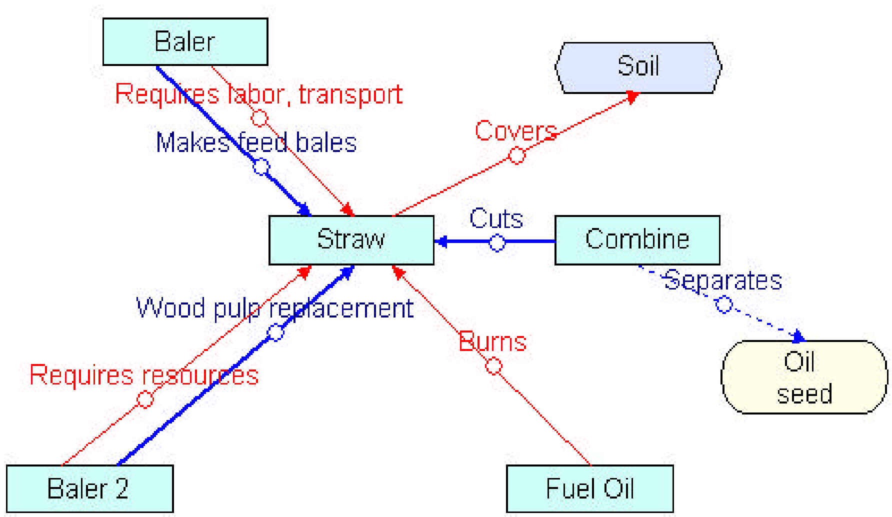

Figure 6. Function analysis model diagram for flax farming. A function is shown as two components and a linking action. Functions can be useful or harmful, and useful functions can be adequate or not.

The function analysis model is also typically created at a single instant in time, with the same consequences as for the operational model; that is, the problem statements are time-independent, which makes them easier to solve, but it may not reflect the reality of the system. Again, note that the modeling system is not really intended to show multiple alternates. Alternates were also forced in this diagram.

3.2 Time Dependent Modeling

3.2.1 Need for explicit modeling of time dependence

Many operational systems include elements or sub-systems that operate over widely diverse periods of time. In such systems change, or sometimes the rate of change, of parametric values of the elements of the system determine functionality. Traditional function analysis models portray static relations between the elements of a system and offer no means to show that elements may change the degree of their interactions over time, and may even have no effect on any other element of a system for significant periods.

For systems in which time dependency dictates functionality, useful modeling may require explicit portrayal of that time dependency to guide improvement of the real system. Fortunately various means and methods to develop and execute these models exist.

3.2.2 Using a Causal Loop modeling system

A causal loop model is shown in Figure 7. This methodology is based on the systems thinking discipline developed and popularized by Peter Senge (8, 9). One automated version of this modeling method, the I-Think Software by High Performance Systems, is described in Reference 10, and is among several software products available (11). The modeling method utilizes a nouns and verbs representation of the elements of a system (12). Nouns, represented by rectangles, are amounts, quantities, accumulations, things, states of being, or levels, etc. The verbs are activities that cause change, either positive or negative, in the magnitude (condition) of the nouns. Verbs are shown as directional pipes or flows, with regulators.

Additional graphic elements are useful in representing causal link model elements. First is the cloud, which can serve as an infinite source or sink for the noun elements. This allows models to be bounded for practicality, and allows a focus on sub-systems of particular interest. The second additional element is an action connector, shown as a solid curvilinear arrowed line, to show causal linkages, inputs or outputs, between model elements.

A clear distinction of this modeling system versus those above is that it not only shows dynamic coupling and linkages, it shows the changes of importance of the different factors being modeled over time, and provides for alternate operational paths within a model.

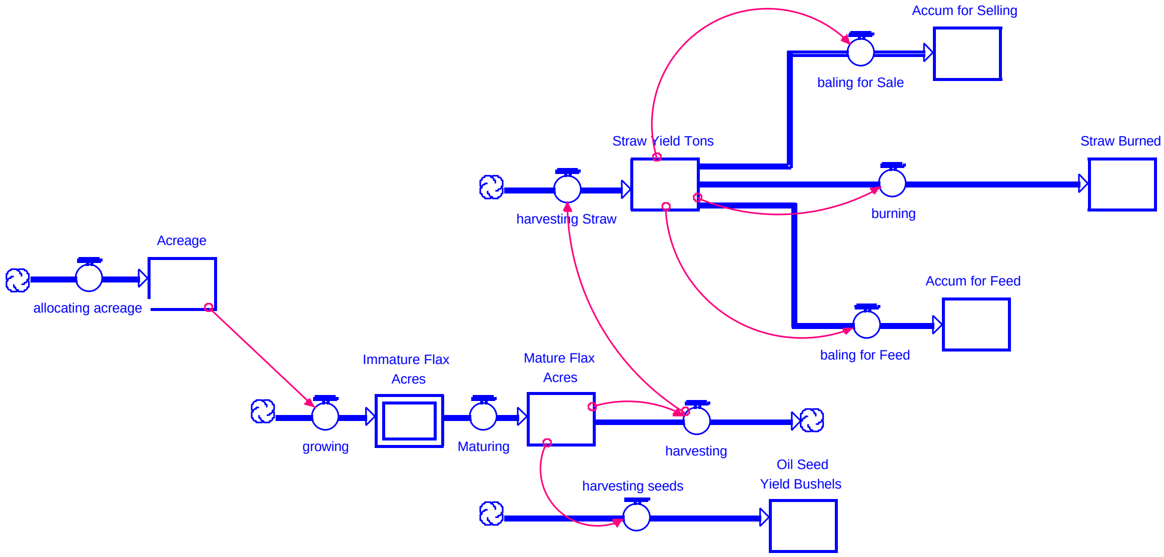

Figure 7. Causal Loop Model of Flax Farming

The result of operating this model, for a particular set of parametric inputs (acreage, seeding and growing durations, and levels of demand for both process straw stocks and fodder for livestock) is shown in Figure 8. These curves clearly demonstrate the variation in strength of causal factors over time, and may help reveal secondary effects not previously perceived.

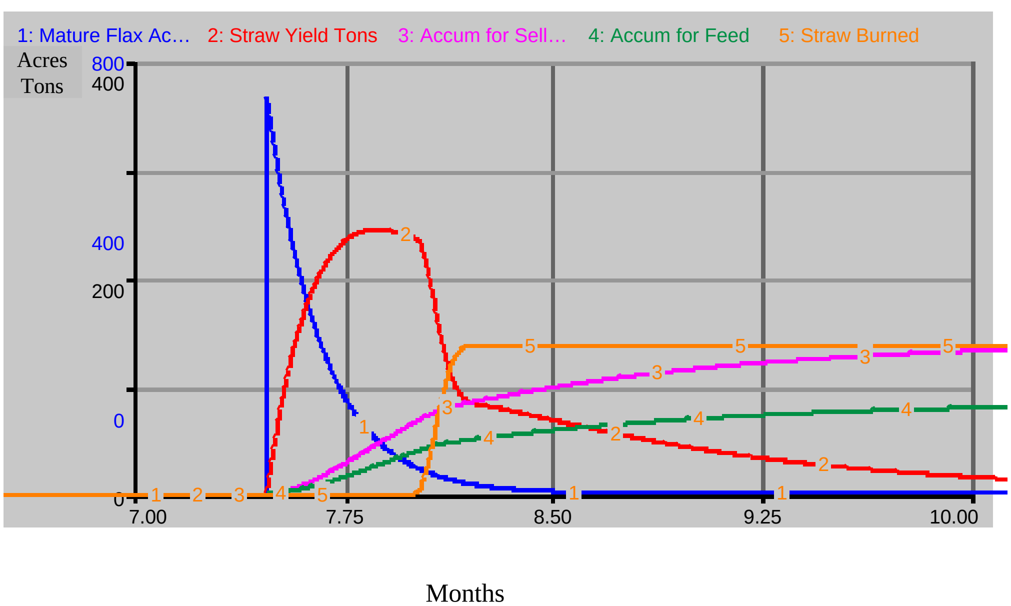

Figure 8. Output of the Causal Loop Model

This model output in Figure 8 makes it very clear that different problems need to be solved at different times in the year, and under different circumstances. Noise factors, outside the control of the farmer, have considerable influence on the outcome of the process. Such noise factors include rain, other weather conditions, and the market for both the flax seed and the straw. The farmer can influence, although not fully control, certain other factors such as soil moisture and soil fertility. The problems to be solved and the relationships between the solutions can be explored over a range of time and noise factors. See Figure 9.

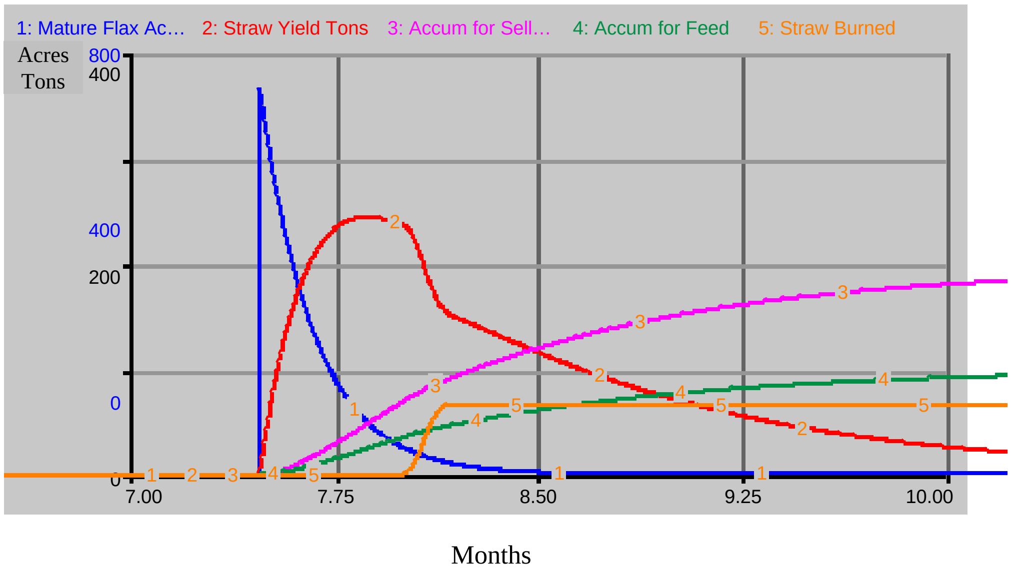

Figure 9. Output of the Causal Loop Model for certain ranges in market price of straw and demand for feed for cattle

3.2.2 Need for complete modeling of time dependence at different levels?

Review of the modeling results above showed that even if complete data existed about variations in environmental factors, market conditions, straw and oil demand, etc, to make decisions in a single year context, other conditions / constraints that operate over a multi-year horizon control many decision points. Constraints of crop rotation programs, available acreage, market demand for other crops, all combine with multiple assumptions about anticipated market demand months and years in advance of actual commitment to a planting program.

In order to effectively model a system which actually operates over a multi-year cycle, it is necessary to change the level of detail, and include system elements at a greater level of aggregation for decision making. These models continue to be developed.

3.3. The hierarchy of models of the system

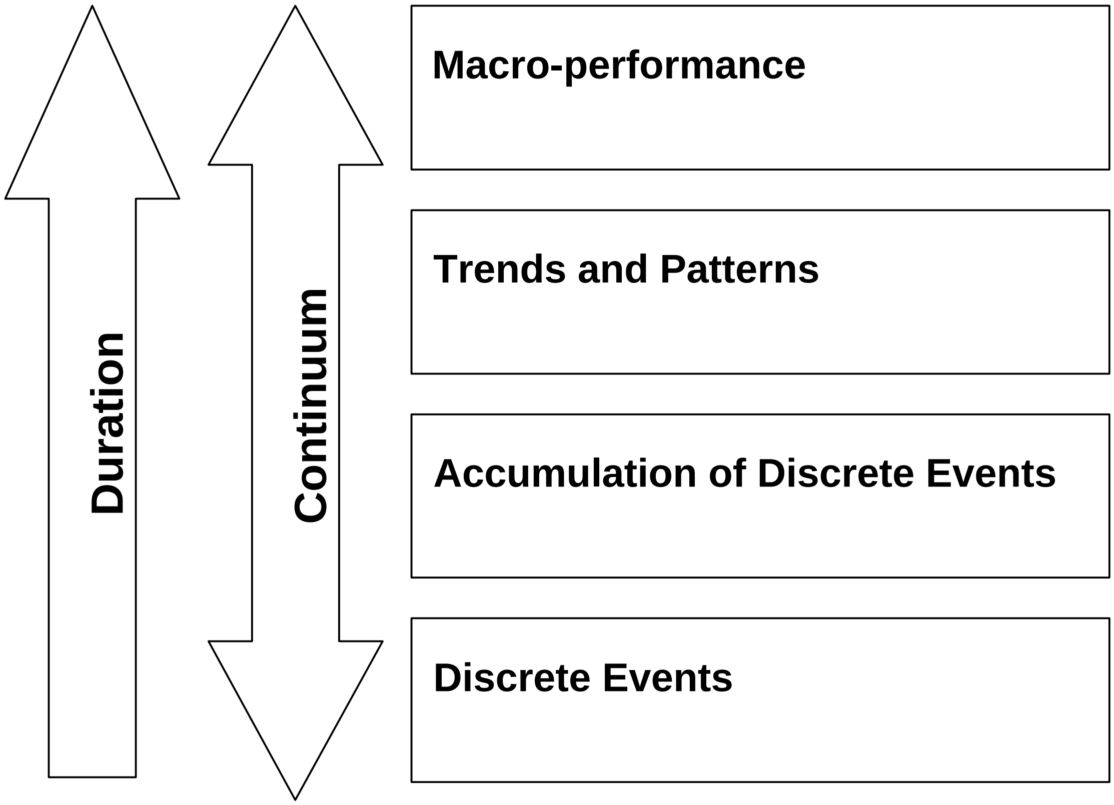

Figure 10: A pictorial representation of the hierarchy of models of systems. There is continuum of complexity levels ranging from discrete events (typically of short duration) through the accumulation of discrete events, to the developments of trends and patterns (typically over longer periods of time, since several cycles of accumulation are necessary to begin to see a pattern) to the macro-performance level, at which the system dynamics and relationships can be seen over an extended time period, and in relationship to the time-varying performance of the external environment.

Figure 10 shows the pictorial representation of the hierarchy of complexity and duration that describes the nature of system models (8, 9, 10, 11). This representation is reminiscent of the System Operator (3, 4, 5) and somewhat reminiscent of the DTC (Dimension/Time/Cost) Operator in TRIZ (1). It is possible to build valid models of the system at each level, but until models are built at all levels, the performance of the system over time and in the functioning environment won't be effectively represented.

Altshuller's definition of a system can be used at each of the 4 principal levels of the hierarchy:

- Tool
- Object
- Energy by which the tool affects the object
- Transmission by which the energy is linked to the objects
- Guidance and control method, by which the system functions.

Table 1 shows that systems, using Altshuller's definition, are operating at each of the levels of the hierarchy. The reader can easily create several more levels between each of the levels shown. Complexity increases over the continuum; the four levels were introduced for convenience of discussion.

Table 1: System elements for each level of the hierarchy, using the flax harvesting case as an example

	Macro-performance ((fiber commerce)	***Trends and Patterns (operating a farm)***	***Accumulation of Discrete Events (harvesting a field)***	***Discrete Events (cutting a plant)***
Tool	Processing factory and supply system	Farmer	Combine	Cutter
Object	Farm	Farm profit	Field	Flax plant
Energy	Demand pressure from world market conditions	Investment	Mechanical	Mechanical
Transmission	Price of flax fiber	Disposal of straw	Cutting and separating mechanisms	Blade
Guidance and Control	Markets	Decisions on how to remove straw from field, based on financial and agricultural information	Machine operator	Machine operator

4. CONCLUSION

None of the conclusions reached in this study will surprise experienced TRIZ practioners and TRIZ teachers. The tools, techniques, and methods demonstrated here for organizing information may be useful to all who try to apply TRIZ to complex situations. The application of several kinds of modeling methods to the problem of the Saskatchewan farmer making the decision about how to remove flax straw from the field has demonstrated the following:

1. The more depth and breadth of modeling, in dimensions of time, space, economics,

society, energy, etc., the more choices about the solution level as well as the solution itself will be developed.

2. TRIZ tools, such as function analysis models (subject-action-object models and formulator models) are useful at many levels, but each individual model should be created at only one level. Not shown in this paper, but suggested by many people who have tried this, is the use of a map (tree diagram or table) for organizing the models and keeping track of the TRIZ problems and solutions associated with each level.
3. Tools from other disciplines that specifically incorporate time dependencies can be added to the TRIZ "toolbox" easily, to aid in developing the insight necessary to formulate the TRIZ problems.
4. Altshuller's 5-element system model is useful at all levels of complexity, to define the system at that level. In use, it is an excellent facilitation tool to help teams develop common definitions of the operating elements and flows of energy and information in their system. People who have been using the formulator model diagram or the subject-action-object diagram as facilitation tools will find this table to be a useful supplement. The table of model hierarchy may be particularly helpful when there is a de-coupling or shift in the very nature of an element of Altshuller's model as the hierarchy levels change.
5. A new problem may be encountered, at a high level of complexity, when the very act of observing / improving large and time distributed systems changes the situation, while the system is operating.

The richness of TRIZ has expanded in the past as techniques were imported from value engineering, system engineering, and strategic planning methodologies. That richness will continue to expand both as more methods are used to increase the depth and breadth of problems that TRIZ addresses and as the ease of using the TRIZ methods increases the variety of people who can benefit from TRIZ.

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