ON THE RULES OF THE GAME IN SYSTEM DYNAMICS

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I. Strategic evaluation

Although strategic planning originates from military use and from business corporations, any social group may be the object of strategic analysis in Business Economics. The process begins with a definition of the purposes and values of the organization (Rowe, Mason & Dickel, 1982). In this case the focus of our interest will be the SD community.

My interpretation of the discussions at the 1981 System Dynamics Research Conference is that the purposes and values of the SD community can be summed up as "growth for survival". On the basis of such a conclusion, a Grand Strategy can be formulated that shows an integrated approach in the response to a constantly shifting external environment over a period of 5-15 years.

The evaluation of strategic alternatives is based on WOTS-UP analysis, which assesses the weaknesses, opportunities, threats and strengths of the various alternatives. Opportunities and threats are external forces to be balanced with internal resources, i.e. strengths and weaknesses. Let us now see what these four facts are for the SD community.

The future will be completely different from the past. "In recorded history there have perhaps been three pulses of change powerful enough to alter Man in basic ways. The introduction of agriculture....The Industrial Revolution....(and) the revolution in information processing technology of the computer...." (Simon, 1969). The information society to come is a great challenge as it will create many opportunities (Martin, 1980). It is to be expected that the production of information values and not of material values will be the driving force behind the formation and development of society (Masuda, 1981).

The major threat comes from competitive methodologies which allow for "mass production". New user-oriented tools, like SIMPLAN (Mayo, 1979), have already arrived on the market as the life-cycle of "computerized models" has now reached the growth stage. For example, by 1980 a conservative estimate of companies using econometric models of Chase Econometrics, DRI, and Wharton was between

750 and 1000 (Naylor, 1982). At the same time, the methodology of SD was still of the unit-production-type.

The strengths of the SD approach are as follows: explicit use of causal relations, the admission of qualitative information into the model and the potential for methodological 'merges'. The drawback of the methodology is that it is difficult for the uninitiated and considerable effort is required in the modeling of SD.

The purpose of strategic planning is to find a new product/market combination which accurately reflects the company's strengths and weaknesses. In our case the SD community is the "company"; the methodology of SD is the product and different types of models correspond to market areas.

The SD community is like a company which has chosen the strategic alternative of **concentration** : The focus is on a single product line while the purpose is to do one thing well (Thomson & Strickland, 1981). How might this strategy be changed in order to encourage faster growth in the future ? Here again discussion in strategic terms is helpful.

One can choose from existing products, improved products and new products in the product/market scope. To minimize the weaknesses the product should be similar to competing products especially in the features where competitors are better or are generally believed to be better. There are only a few competitors (competing methodologies) to system dynamics and, therefore, the pressure to be similar is obvious.

However, ultimate success is based on competitive superiority which exploits inherent strengths. In place of the concentration strategy, there is a need for a **diversification** strategy, leading to new products. I will start the standpoint of weaknesses because they can be converted to strengths.

Through a systems theory, the modeler anticipates from the observed reference behavior what kind of structure the model should have and then tests this dynamic hypothesis via simulation. The role of systems theory is so important that I will discuss it separately as the **Proposition of SD :**

A SYSTEMS THEORY IS NEEDED TO FIND A FIXED MODEL STRUCTURE

Since model structure causes model behavior, once the reference behavior is given system dynamicists focus on finding the right structure with the help of systems theory. The model should produce the reference behavior. They call this "educated guess" the dynamic hypothesis and computer simulation will then show whether the guess was acceptable or whether it needs revision.

Dynamic hypothesis interrelates a coarse model **formulation** with the anticipated **solution** of the model, i.e. with plotted data from simulation.

By binding model formulation and model solution together at the stage of dynamic hypothesis, systems dynamicists make higher demands on professionalism than is made in other methodologies. This consitutes a weakness in competition.

I now propose the **Anti-Proposition of SD** as a constructive solution to the problem:

A SYSTEMS THEORY IS NOT NEEDED FOR FINDING A VARIABLE STRUCTURE

The purpose of this paper is to show that the Anti-Proposition of SD is true and that it can lead to an operational approach.

By abandoning the systems theory as the guide to modeling, the modeler can separate model formulation and model solution from each other as he need not guess the solution at the formulation stage. This is possible if one allows the computer to seek new solutions.

This may be a difficult paper for systems dynamicists to read because the established way of thinking is replaced by a new way which may appear counter-intuitive. They will find that some old concepts are no longer needed and that, at the same time, many new concepts are created. I should like to cite one example: loop polarities are of little use and model robustness is replaced by the concept of model vulnerability.

Figure 1 shows the relation of formulation to solution and, at the same time, points to the difficulties that lie ahead. The move from the old way of solving a problem to the new is a major change but a move towards a new way of formulating and solving a problem involves a lot more.

		Formulation	
		old	new
Solution	old	SD	-
	new	?	RD

Figure 1. The relation of formulation to solution

The proposition of SD requires an aggregated approach where formulation and solution are intermixed. As this is the starting point, SD was placed in the matrix cell 'old,old' in figure 1.

The cell 'old,new' refers to a situation where the computer is being used in the same way as before but model formulation differs from the current practice. However this choice is not feasible as it is nearly impossible to find an acceptable structure by trial and error alone. It is like trying to generate the right sequence via the Monte Carlo simulation.

For competitive reasons, model formulation should be 'similar' to linear programming and econometrics. By 'similar' I mean the gradual row by row approach which allows the modeler to forget the 'big picture' that is so important in SD and in Operations Research.

The cell 'new,old' refers to the case where the computer helps in evaluating how good the dynamic hypothesis is and might also show the likely directions for change. Should we still call the new way of doing things SD and say that the paradigm of SD has not changed ? These questions are fundamental and have to be discussed.

Finally, the cell 'new,new' indicates an indisputable departure from the past and deserves a new name. I shall refer to it as **Relativity Dynamics (RD).** The word 'feedforward' means that optimization is based on a forecasted deviation of information:

Relativity dynamics is a feedforward-based methodology which emphasizes full-adjustment and extended human-machine co-operation in a heuristically optimizing framework.

Why use the name relativity dynamics then ? To answer this question, we have to return to the concept of knowledge. While Aristotle was interested in the unchanging properties of things, Galileo was interested in the unchanging relationships of things. In relativity dynamics, even the relationships need not be unchanging and this supports full-adjustment. Since the subject matter of change is highly advanced, I will defer a more detailed discussion of it until the last section of this paper.

SD focuses on generic structures (Bell&Senge, 1980, p.66). In RD, model formulation and model solution have been separated from each other. RD focuses on generic procedures for receiving solutions and on specific formulations. This means that a division of labor between the modelers is now feasible. There is a need for specialists in substance and for generalists regarding the solution. Even additional division of labor is possible between those modelers who are formulating the problem as they are allowed to see the problem in different ways.

This leads to **group formulation** which corresponds to group decision-making where modelers interact with each other. For Example, Emshoff (1978) believes that the evolution of managerial models in the 80's will lead to an 'Experience-Generalized' mode where "a key function of managerial interactions will be to share relevant information so that differences in model representations of problem environments can be identified and resolved."

The first commercial applications with computers were based on efficiency: the computer replaced some clerical work but the system remained the same as before. Effectiveness came later when computerized systems were redesigned in order to attain new goals. In the same way, the iterative modeling work can be made systematic while retaining the prevailing modeling practice in SD, or the modeling practice may be completely revised.

Should we now call the 'new,old' alternative SD or RD ? SD emphasizes the modeling practice but RD is the right name if one wants to stress heuristic optimization and the new role of the computer. The first choice might appeal more to the systems dynamicists of today; the second choice might be more appealing to future dynamicists. As the strategic viewpoint emphasizes the future aspect, I prefer the broader interpretation of the word 'relativity dynamics'.

Does the paradigm of SD already change in the cell 'new,old' or in the last cell 'new,new' ? Again the question is of interpretation. In both cases the modeler has to rely on his own judgement and the algorithms given to the computer but the utilization of technical possibilities varies. Should we now emphasize the basic move in trust from man to machine or the actual use of more advanced potentials ? I prefer the first choice as it is more fundamental.

II. Implications for modeling

1. The current situation

Modeling can be divided into the strategic, tactical and operational stage. In the strategic stage, the modeler chooses a modeling strategy and a descriptive strategy. The modeling strategy outlines the approach to the problem. The purpose of

the descriptive strategy is to provide a visual impression of the model. The tactical stage concerns the structure of the model; the operational stage transforms the chosen structure into a computer model.

The holistic approach and focused approach are opposites in modeling strategies. The first is the traditional way of attacking problems and it starts from the "big picture". In the second approach, only a few variables give the starting point for a gradually growing model (Coyle, 1977). The third possibility consists of applying the first strategy to each major part of the model separately and then combining all the submodels. Even this splitting-approach is well-established in SD.

Descriptive strategies are based on feedback and/or recursiveness, which are basic properties in SD. Influence diagrams are based on feedback and their weaknesses have been pointed out by Morecroft (1982). Flow diagrams utilize special SD symbols and emphasize recursiveness but at the cost of the total picture. That is why many hybrid improvements have recently been offered:

- Sahin gives an example where the influence diagram was modified by adding the material flows later and then the flow diagram symbols (Sahin, 1978)

- construction of the flow diagram by starting from level variables (Sahin, 1978)

- two-stage description which includes the subsystem diagram and the Policy-structure diagram. (Morecroft, 1982)

- modular approach to flow diagrams (Coyle & Wolstenholme, 1981).

The tactical stage relates to construction of the model structure. Causal relations are found using various methods (Coyle, 1977) and the polarities of the feedback loops, either negative (balancing) or positive (growth), are determined (Goodman, 1972).

As model structure causes model behavior, knowledge of some generic structures and their properties helps in determining what kind of structure the specific model should have. The teaching of generic structures is the most important single part of any SD curricula (Andersen & Richardson, 1980). Graham's dissertation (1977) has so far been the most ambitious effort for developing needed structural material for systems dynamicists.

Figure 2 summarizes the stages of model-building in SD.

Strategic stage
* Modeling strategy
** Holistic approach
** Focused approach
** Splitting-approach
* Descriptive strategy
** Influence diagram
** Flow diagram
** Hybrid diagrams
Tactical stage
* Dynamic hypothesis
Operational stage
* Programming

Figure 2. The stages of modeling in SD

2. New approaches

I have briefly discussed modeling strategies earlier, and from the standpoint of the prevailing situation in SD. RD gives more depth into this discussion as it distinguishes problem formulation from problem solution. From now formulation strategy will be used for what I previously called modeling strategy. Solution strategy refers to a major alternative in solving the model.

A. Simplification

As the model simplifies reality, three types of errors are likely to occur:

(a) some model relations do not correspond to their real world counterparts

(b) some necessary relations are missing

(c) some relations are redundant.

In the SD approach, points (a) and (b) are explicitly covered in all choices of modeling strategies. Point (a) is relatively easy to deal with by observing, inquiring and discussing. Model output is used to ensure that point (b) does not cause any problems; if the dynamic hypothesis is wrong, the model does not behave as it should. Finally, all agree that the model should be as simple as possible but only the methodology of RD gives a systematic solution to this requirement.

When a problem is being formulated, the process continues until the model behaves in a proper way. Any of the traditional choices (holistic, focused or splitting-approach) may be used for this purpose. When the model is being simplified it behaves in a proper way as long as the simplifications are justifiable. Figure 3 illustrates the relationship of errors (b) and (c).

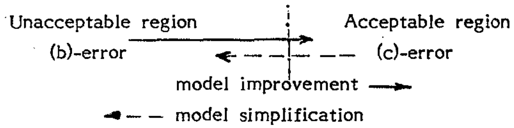

Figure 3. The contrast of improvement and simplification

Simplification means cutting off some flows in the model. In systems jargon, it is the same as reduced state modeling and, in econometrics jargon, it is called identification. Even philosophers have an expression of their own as they talk about the relevancy problem. The word 'simplification' was chosen because it is not 'biased' towards any discipline.

The concept of solution-strategy can be illuminated by first defining two 'soundness'- concepts and by referring to heuristic optimization in the definition of relativity dynamics in Part two above. The expression 'simplicity soundness' refers to the simplicity of the model structure and 'numerical soundness' refers to the value of the objective function in optimization. For Example, the smaller this value is in a minimization problem, the 'sounder' the solution is. Model improvement can thus be described as a combination of two 'soundness' measures, as in figure 4 below.

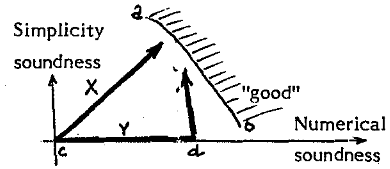

Figure 4. Model soundness and its components

The indifference curve a-b represents a hypothetical boundary for acceptable model soundness which is thus a two-dimensional concept. The indifference curve a-b is a goal to be attained.

The vectors X and Y show two ways of achieving the goal, which is "good". The both are dynamic solution-strategies as they describe trajectories from an unsatisfactory model to a model that is acceptable. Those strategies are also pure because they either improve the model structure and simplify it simultaneously or do it succesively. Mixed strategies are of the following type: follow strategy Y to some point between c and d and from there follow strategy X.

The short review of descriptive strategies indicated a trend from influence diagrams towards some hybrid modifications. The criticism of Morecroft (1982) against influence diagrams can be summarized by saying that they are not helpful enough in the formulation of dynamic hypothesis. But if we abandon dynamic hypothesis, the influence diagram or some new version of it may be very useful as a descriptive strategy.

B. Forget the feedback

RD reformulates the tactical stage by replacing the dynamic hypothesis with the transient hypothesis (Keloharju, 1981). The transient hypothesis is a byproduct of a heuristic optimization process where the computer finds models of ever improving quality in objective function terms. Each version is a transient hypothesis until it has been replaced by a better one. Now we have a 'dynamic' hypothesis which is dynamic in the sense that the hypothesis itself will change continuously during the optimization process.

The elements or building blocks of the model have to be defined for model formulation stage. This step can be made easier if we construct a matrix (**influence matrix**) where all possible model variables have been listed as rows and columns.

The matrix will be constructed row by row. Matrix rows are thus those building blocks that are needed. Each matrix line is a general description of some model equation. When the right dynamic hypothesis is a subset of this set of equations, the computer might be able to find it with the help of an objective function.

We can now build models **without paying any attention to the concept of feedback.** Utilization of this fact is probably the only way of breaking down the established isolation of system dynamicists and then to induce a growth-process which corresponds to potentials of the field.

Are systems dynamicists ready to abandon the corner stone of their thinking ? The problem is that feedback is simultaneously the strongest asset systems dynamicists have **and** the reason for their isolation.

Let us now return to descriptive strategies by taking the influence matrix as the starting point. Now the purpose is not to describe the (hopefully) right dynamic

hypothesis but to show all the options that the computer can choose from. Since the methodological viewpoint is similar in strategic, policy and operational decisions, the corresponding equations will be called decision rules.

The idea can be applied to any decision rule by dividing the rule into its components. This shows the hierarchical structure of the rule. The picture we receive is called an **option diagram.** The word 'option' refers to the fact that the final decision rule is in some way related to the total structure. It still remains to be seen in which way it is related. The option diagram is best described with a small example.

Coyle and Sharp (1976) give the following description where the memnonic symbols have been added from the influence diagram which the authors present.

Production Order Backlog (POBL) depends on Production Order Rate (POR) and Production Rate (PR). Production Rate depends on Production Order Backlog and a time constant τ_1 . Inventory depends on Consumption (CONS) (which is exogeneous) and Production Rate. Average Consumption (ACON) depends on Consumption and an averaging period τ_3. Desired Inventory (INV) depends on Average Consumption and weeks Cover Desired - a constant r. Production Order Rate depends on Inventory (INV), Desired Inventory, Average Consumption and an Inventory Correction constant τ_2.

The influence matrix below shows the causal relations between the model variables. It contains the same information as the conventional influence diagram. For example, INV=f(PR,CONS).

	INV	PR	CONS	POBL	POR	DINV	ACON
INV		1		1			
PR				1			
CONS							
POBL		1			1		
POR	1					1	1
DINV							1
AVCON			1				

Figure 5. An example of influence matrix

An option diagram can be assembled by starting from any variable in the influence matrix, assuming that this variable is not exogeneous. With the option diagram, the modeler is able to see his problem as if it it were formulated as an open model.

Below we have two versions, starting from inventory INV and Production Order Rate POR.

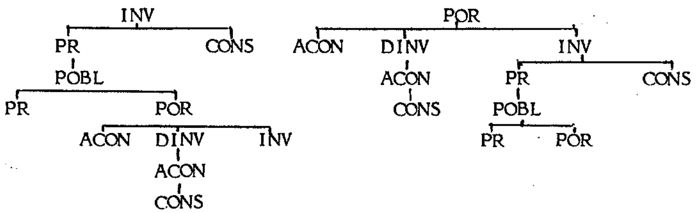

Figure 6. Two alternatives for the option diagram

An option diagram relates both to the strategic and to the tactical stage. At the strategic stage, the option diagram is one of descriptive strategies. At the tactical stage, it allows the modeler to focus on any model variable, like INV and POR. This is a methodologically valuable property when the model has an objective function.

At the tactical stage, the option diagram allows the modeler to choose both the **form** and the **content** . Two form-related options were given above. Content-related options cut-off some branches of the option diagram when the influence matrix has some redundancy. For example, should the decision rule for POR include only inventory correction or the Average Consumption ACON too ? The answer is found at the operational stage.

Figure 7 shows that a new concept, A1, controls the choice related to the term ACON.

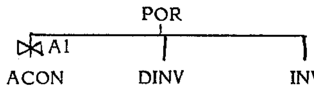

Figure 7. An option has been specified

C. Parameters in a new role

A variable model structure results from weighting some branches of the option diagram with additional constructs, called decision parameters. For example, Production Order Rate above might be defined as follows when multiplier A1 was missing from the original equation.

$$POR.KL=A1*ACON.K+(DINV.K-INV.K)/\tau_2$$

In SD, parameter changes which do not cut off information flows are likely to be inefficient because ordinary model parameters have no connection with unknown leverage points. The use of decision parameters, like A1 above, changes the role of structural changes as a likely requirement for improved model behavior.

The use of decision parameters supports a new interpretation of the concept of structural change by focusing on information use. Keloharju (1980) has shown that there are three kinds of information use to choose from:

(a) Constant use. Information sources and information weighting remain constant

(b) Mixed use. Information sources remain constant but the weighting varies because of relative changes in structure

(c) Variable use. Information sources and weighting vary because of absolute change(s) in the structure.

Let us now return to the POR-equation above. An absolute change in the structure can be made by giving A1 the value of zero or τ_2 the value of infinity. But we can always find a relative change which is as efficient as the nearest absolute change is. Assuming the removal of the ACON-term drastically changes the model behavior (as in fact it does) we may give A1, e.g., the value of 0.001 and thus have only a relative change.

Optimization through transient hypothesis is an iterative procedure where various relative changes and some absolute changes in the structure are being tried. In many cases an absolute change in structure is only a 'cosmetic' change which simplifies the model structure. In RD, the suitability of this procedure can be examined using a structural sensitivity analysis (Keloharju & Luostarinen, 1982).

At the strategic stage, we encountered pure and mixed model-solution strategies. The same classification reappears at the tactical stage but this time in a static rather than a dynamic sense. Suppose that two decision parameters, B1 and B2, may replace each other. We can now interpret them in terms of decision analysis and replace B2 by 1-B1. This suggests the use of the B1-related term B1-portion of time and the B2-related term the rest of the time.

The strategy is pure when either B1 or 1-B1 is selected; otherwise it is mixed. When the transient hypothesis begins with the value for $0 \leq B1 \leq 1$, and ends-up, either with or without simplification, with B1 having either of the extreme values 0 and 1, the change in the structure is absolute.

Systems dynamicists can only deal with changes in individual parameters. To quote Starr (1980): "Changes in groups would introduce an overwhelming number of combinations and hence are never done on an all inclusive basis".

Dynamicists have learned that parameter changes alone are usually inefficient. In my own terminology, this means that parameter changes in SD are insufficient relative changes in the structure. The situation can be corrected by adding decision parameters to the model.

III. Support for relativity dynamics

In the first part of this paper, I evaluated the SD culture from the strategic viewpoint. Since there is a need to revise the SD paradigm, I stated the counter proposition of SD and in Part two explored the implications of the new paradigm for modeling. In this part I will first be discussing the forces which affect whether the model is accepted or not. To be specific, I assume a Management audience. A short description of required software changes is then given as then the problem is how new Man-machine relations affect model evaluation. Figure 8 summarizes the key relationships.

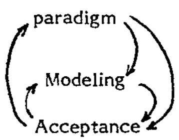

Figure 8. The mutual relationship of paradigm and acceptance

Control theory, SD and RD differ from each other in the mathematical demands they make on a modeler. The control systems theory has not been widely used by system dynamists and this appears to be due to its mathematical sophistication. But the price the system dynamists pay is their uncertainty of the soundness of their solutions because they simulate instead of optimizing models. The same exchange of values occurs between SD and RD: mathematical sophistication decreases again but at the cost of solution-related uncertainty.

Which of the three approaches is preferable ? Could I suggest that the best approach minimizes the total uncertainty of the decision maker when he does not fully understand the model and may not receive "water proof" results from the model? Let us now look at 'understanding' as it is a necessary condition for acceptance.

1. Acceptance

In order to anticipate management attitudes to model evaluation in the future, we need a kind of stakeholder analysis. In ordinary stakeholder analysis, the supporting and the resisting forces brought to bear on the organization include owners, customers, employees etc. But at a higher level of abstraction, we deal with cognitive forces effecting decision-making. These 'stakeholders' include the manager himself, the firm he works with and the society he lives in. Let us see what their likely effects will be.

Society is becoming more and more a society of institutions. Peter Drucker (1980) has described what this means to management:

"In a pluralist society, all institutions are of necessity political institutions. All are multi-constitutiency institutions...the managers of all istitutions will have to learn to think politically in such a pluralist society....one tries to find a solution that will not create opposition, rather than one that will generate support. Satisficing is what politicians mean when they talk of an "acceptable compromise"."

At the same time, cultural segmentation is taking place. This process has only started but it is going to characterize the information society. Toffler (1980) calls segmentation de-massification and then argues that "the de-massification of the media de-massifies our minds as well". Therefore, we live in a "blip culture". In this environment it will be compulsory for everyone to try to form a synthesis from the abundance of information. Some will manage to do this only superficially but some others more deeply.

He assumes that Third Wave people (those who feel easy in the information society) "... also keep an eye out for those new concepts or metaphors that sum up or organize blips into larger wholes". This can be interpreted both positively and negatively. At best the blip culture creates attitudes which are based on deeper understanding of synthesis, supported by analysis. At worst, the blip culture fosters superficiality. There is no reason to think that future managers would not belong to the first category.

The pluralist, blip-cultural society creates an environment where synthesis of information is a way of life for managers. As computers can help assemble "blips" into larger, more meaningful wholes, the attitudes towards computers are likely to change. Computers are not seen as servants any more but as peers.

The changing attitudes are one aspect of, what Masuda (1981) calls, "the Spirit of Neo-Renaissance". Liberation of the human spirit fosters intellectual creativity as well as curiosity. It is safe to predict that this shift will profoundly affect man-machine relations.

De-massification also affects the firm when a new wave of 'decentralization' comes into being. Drucker (1980) expects that multinational corporations will be superseded by transnational confederations, which are based on the concept of production sharing. This is global subcontracting which strives for balancing labor deficits in developed and labor surpluses in developing countries. Transnational corporations are likely to be marketing and management companies rather than manufacturing companies.

Drucker further assumes that the nature of management will change:

"It will be increasingly difficult in the organization of tomorrow to distinguish the "middle manager" from the "senior professional", and both from people who do top management work...A transnational confederation is a "systems" organization in which there is not one but a great many "top managements", and in which almost everybody in charge of a specific piece of the whole has to understand all the decisions about the entire enterprise so that he can function constructively".

'Decentralization' leads to increased 'cognitive demand' for experimentation and increases demand for surveillance systems. The new blip culture and liberated human spirit create 'cognitive supply'. By experimental confidence, I mean that the 'right' model has been found by experimentation and then accepted. The new culture and the new spirit reinforce each other and thus support favourable attitudes towards experimental confidence.

But SD and RD are the opposing approaches to achieving experimental confidence. In SD, the solution of the model follows an understanding of the problem (Bell&Senge, 1980, p.70). In RD, the solution can **precede** it. Actually the modeler has many alternatives to choose from:

(a) use of traditional SD

(b) supplement the approach above with a systematic sensitivity analysis of RD

(c) use first the approach of RD and then develop a dynamic hypothesis

(d) use of RD.

I argued in part one that the product should be similar to the competing products in those aspects where competitors are better or are generally believed to be better. In part two I showed that the separation of the solution from its formulation creates the needed similarity. I believe that this is the right direction in which to go but it is only the beginning.

We might **use computers to analyse automatically results** from optimization in order to help the modeler gain the understanding, and in this way the acceptance, of the audience. Conceptually, the procedure reminds us of the 'conversion' of the influence matrix, which means that the Man-machine loop now closes. This is a challenging new role for systems dynamicists and in my mind I can already hear loud voices of suspicion. Therefore, let me briefly review what has been done so far for the Man-machine interrelation in RD.

2. Software changes

System dynamics is a resource-oriented approach. In the real world, some resources are combined to create a product but the same also applies to the modeling world. Then the 'material may consist of computer software. System dynamicists use a special purpose language (Dynamo or Dysmap) and their modeling process can be described schematically as follows:

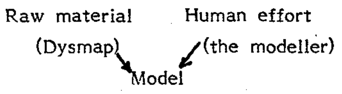

Figure 9. Modeling in system dynamics

We now need an optimization algorithm as a guide to the modeling process in RD. The optimization procedure is heuristic, i.e. based on trial and error. Although a search process is needed for problem solution, the process simultaneously gathers information about the structure behind the solution. Searching is based on the idea that an exhaustive synthesis is unattainable and, therefore, samples have to be taken.

The heuristic optimization algorithm involves some additions to the software. This extension is called the **Frame.** The frame is problem-independent but the model, of course, is problem-related. Between these extremes we still have a third group: problem-type dependent **replacement modules** . They are algorithms which assist the computer in the modeling work. As replacement modules have a lasting value they should be saved and 'recalled' when needed.

When a model is solved, the computer generates some 'results'. If these results, when measured against given objectives, are not satisfactory, either the model or the solution-procedure should be changed. At this stage, some other replacement module may be tried.

The modelers' role in the division of labor is now clear. Some modelers specialize in model-building; others specialize in model-solving (Keloharju, 1977). Figure 10 shows the relationships discussed. The dotted lines indicate corrective measures.

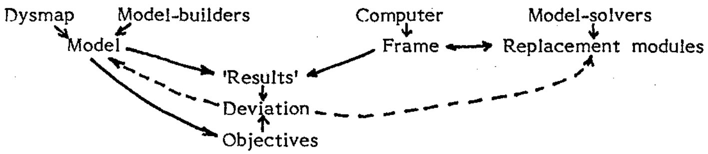

Figure 10. The role of different modelers

Dysmap, the Frame, and replacement modules form an integrated package, called DYSMOD (Dynamic Simulation Model Optimizer and Developer, Luostarinen, 1982). The concepts of Frame and replacement module may sound strange but they only extrapolate a process currently in operation. The post-industrial stage can be divided into two parts on the basis of repetitiviness and abstraction level. Repetitive work in the real world relates to the micro-processor age where machines guide themselves. Non-repetitive work, occurring in the model world, requires computers to guide the modeling process. That stage is called the software age. Figure 11 compares the micro-processor and software ages in analogous terms.

Micro-processor age:	Software age:
Programmable silicon chips	General frames
Programs to be attached to silicon chips	Removable computer programs
Micro-processors	Models
Self-guidance of machines	Self-guidance of a modeling process

Figure 11. Some analogues from the post-industrial stage

Shared modeling responsibility with the computer will change scientific traditions because earlier restrictions on model-solving have now been partially removed. When the scientific method was invented, all models had to be greatly simplified. Otherwise man would not have been able to solve them. Now computers find approximate solutions to even highly complicated models. They may then be simplified but simplification is not any more a precondition for model solving.

If a model does not pass the validation tests in SD, it is in error and has to be corrected. Replacement modules add another possible source of error. By way of illustration, let us suppose that the SD model is a good representation of reality but the computer calculates erroneously for some reason. In the same way, the replacement modules may function unsatisfactorily. If that happens, the flaw may not necessarily be in the methodology or in the model and it must be corrected.

Science and beliefs were quite distinct entities in the past but not any more as the counter proposition of RD cannot be proved or disproved. This points to the emergence of a new scientific ideology. But people do not change their ideologies easily. The switch from one paradigm to another is an emotional conversion experience and cannot be resolved by proofs. In his Industrial Dynamics, Forrester warned that it would be a long time before his ideas were generally accepted. Here the same warning is even more justifiable.

Even if the model is 'right' to the extent that it should be used, the acceptance of the model may be more difficult than before. It requires a lot more maturity to accept a result as such, and without resorting to the 'best-solution illusion' of conventional optimization. The decision regarding acceptance now rests with the modeler and it involves a new responsibility.

IV. Challenges

1. Recursive estimation

Technically the difference between SD and RD is based on the role of the computer but philosophically it is based on the attitude of perfectionism. The new role of the computer shows in the division of labor and this point has already been discussed. To see the second dividing line, we have first to define the expressions **internal** and **external** perfectionism.

By internal perfectionism I mean the effort involved in finding the right causal relationships behind some real life behavior. External perfectionism means correspondingly the effort involved in finding for right correlative relationships to the observable effects, deriving from the causal relationships. The SD approach belongs to the first category and the econometrics approach belongs to the second.

Both kinds of perfectionism have been criticized. Legasto and Macariello claim that in econometrics " an unrealistic degree of perfection is needed in prior knowledge about structure and the purity of data to keep the statistical data-analysis results from being indecisive or actually misleading" (1980, p.34). But systems dynamicists can also be criticized as they allow "unobservable" hypotheses (Bell&Senge, 1980, p.68), which are impossible to validate statistically.

Relativity dynamics tends to avoid both the perfectionism and the critics of perfectionism by extending the use of forecasting. All SD models forecast the effect, i.e. reference behavior. When this 'forecast' is self-fulfilling, model behavior imitates the reference behavior by corrective mechanisms which are based on exponential smoothing.

In his "Principles of Systems", Forrester (1968) separates systems from environment with the concept of closed boundary. Closed boundary consists of the 'outer walls' of those feedback loops which constitute the model. Feedback loops are thus like rooms or combinations of rooms in the diagram of a house.

According to the 'purist' interpretation of SD, the closed boundary defines a model and the model is tested only with abstract test-inputs (step, sine). They show whether the stability of the model is acceptable or not. The model of a purist is thus a black-box without an input but with the given output to be forecasted.

The 'non-purists' accept the idea that real life inputs may be a vital part of the model. Further, it depends on the approach of the modeler as to which parts within the closed boundary are controllable. It is for this reason that Coyle (1977) distinguishes between the controller, the environment and the complement. The closed boundary now consists of the controller and the environment; the complement includes the real-world inputs.

Even the input forecast tends to be self-fulfilling. Suppose that the modeler uses real life sales data as an unknown input from the controller's viewpoint. By using a sales forecast, the controller may try to improve his own reaction to the output forecast, i.e. the reference behavior. The non-purist approach can thus be seen as a procedure where both the input and output may be forecasted.

Systems dynamicists want to construct robust models, which are models with an optimum structure in terms of model behavior. This perfectionism is removed by even forecasting the optimum structure of the black-box. The forecasted structure is not the global but a local optimum.

Each accepted structure in RD is an estimate which may perform optimally for some but not all major changes. Therefore the model is not robust but **vulnerable** and the structure should be revised during the simulation when needed. Structure is not an absolute but a relative concept and the name 'relativity dynamics' reminds one of this fact.

For systems dynamicists, the model is that system which has been constructed from a problem under study. That system and this model are one and the same thing. To demonstrate the use of RD, I shall take the substance viewpoint by having the name 'model' mean a resource description of the firm for decision-making purposes. The stand combines the 'purist' and 'non-purist' interpretation of good modeling practice as it excludes the test functions from the model but simultaneously requires the use of some realistic test function or functions for model construction.

Input, model and model output in terms of overall goal are the building blocks in RD. The computer searches for new models by forming transient hypotheses with the help of some input and of an overall goal in the form of the objective function. The starting point in this work is a nominal model which was developed from the influence matrix and which did not take account of the dynamic properties of the model.

Model output is received in many forms in RD: as the value of the objective function, as the values of the optimization parameters and as the values and trajectories of model variables. Are the model and the system then the same in RD? Our discussion indicates that they are not the same because of the hybrid role of input.

In systems analysis, the black-box and either the input or output is given. In

systems synthesis, the black-box can be estimated from the input and output. When two of the three elements are known, the third can be estimated. I stated above that all three are forecasts in RD. Therefore it is possible to estimate any of them recursively and in any order by combining systems analysis and systems synthesis. Two examples will demonstrate this in Part IV.4 of this paper.

The deviation between a forecast of any of the three system components and the corresponding component derives from either of the following reasons or from both:

* the background process has changed

* the system component is only an incomplete description of the process.

Since it does not matter whether the real world, the perceptions or perhaps both are the reason for a correction in the structure, the use of the name 'relativity dynamics' gains new strength. In a forecasting system of the reality, the dividing line between the reality and the system becomes indefinite.

2. A new kind of sampling

The blip culture is essentially a **sampling culture** and this fact also should appear in Man-machine relations. In RD, replacement modules guide sampling. Analysis and synthesis may be seen as opposite approaches to sampling, analysis being 'negative' sampling. Analysis scatters samples, synthesis assembles them. I will start from the analysis.

In RD, the modeling procedure is automatic as long as the computer seeks new solutions for the modeler by means of an optimization algorithm. The computer acts as the model generator by changing the model repetitively and under the guidance of some objective function. Here the word 'model' is given a wide interpretation as even a single parameter change transforms the model into another. The optimization algorithm that is being used estimates in which way it should change the model so as to maximize efficiency and then it makes the changes.

Partitioning of a parameter space means that a model has somehow been divided into a relevant and irrelevant part for the purposes of the solution. It is believed that an acceptable solution can be reached by working only with the relevant part. After a change has been made in the model, the boundary between relevant and irrelevant is likely to shift. Philosophically this means a teleological approach which combines truth and relevancy into a consistency criterium (Kuusi, 1974).

The truth is related to those objectives that are being attained and the "real objective function" states the consistency criterium.

In the modeling of 'unobservables', the choices are as follows: describe the background process statistically by probabilities or formulate causal relationships. Both approaches cause problems.

In 1927 Werner Heisenberg formulated the "indeterminacy principle", which states that no quantum mechanical system could simultaneously possess an exact position and exact momentum. The 'unobservable' hypothesis of causal relationships in macrocosmos recalls the indeterminacy principle of microcosmos. A causal relationship could be measured but only by assuming that all other relationships interacting with it do not come into play. But this would 'disturb' the system because the assumption is not true.

The way out of the dilemma is either to deduce what cannot be measured or first to construct a crude model of causal relationships and then to revise this estimate by **sampling** in terms of the consistency criterium.

Any heuristic optimization algorithm partitions the model it tries to solve. It can do that because the planner of the algorithm has stored intelligence in the internal logic of the algorithm. Here the word partitioning refers to a procedure which samples the optimization process. This requires that the procedure be problem-related and that it be linked to the computer. But, when the computer collects information from the modeling process, it can make use of it to upgrade its own performance. In a way we have opened up a way to artificial intelligence.

What kind of sampling procedure in parameter space would change the model in a way that generates the best final solution? Actually this is a two-level sampling procedure because the sampling-rules require some sampled information from the modeling process.

The sampling theory which has been developed in statistics is of an explanatory nature as it estimates whether the population to be sampled has passed certain criteria. But now we are in need of a normative sampling procedure; it should help in finding a solution which is as close as possible to an unknown optimum solution. Some mixture of theoretical development and rules of thumb may characterize the procedure we are looking for.

The purpose of partitioning is to separate the 'relevant' from the 'irrelevant' but

what does relevant really mean? When the goal is to find an acceptable model according to a sampling procedure, the path towards acceptability has no intrinsic value as such. It is quite possible that the most efficient path leads to a severely suboptimum solution. With high efficiency, some necessary parameter changes are likely to be postponed until it is too late to make use of them as another part of the model has already become indispensable. For this reason a partitioning procedure has to show more 'tolerance' than an optimization algorithm would.

The concept of partitioning has an even wider significance. Suppose we are interested in a sampling procedure which tries to maintain the present model behavior, by removing what is irrelevant from the model. This is simplification, and I described it briefly in part two above. We simplify for two reasons: So as to simplify the models and so as to be able to carry out structural sensitivity analysis.

Sampling is not restricted to a parameter space of the ordinary model as sampling may be needed at any hierarchical level. Even the objective function could be sampled in a goal space.

3. New role of time

The Newtonian laws of mechanics were based on a time-concept where time is reversible and uniform. However real time is unidirectional and evolutionary. The Second Law of Thermodynamics, or Entropy Law, maintains that every transformation of a real system produces a change in the universe which is irrevocable. SD is philosophically thermodynamic but it uses the Newtonian time-concept (Perelman, 1980). DeGreene (1980) expresses the same idea very simply: "Thus, the basic cybernetic theory of which system dynamics is one important part is excellent for describing how systems behaved the way they did in the past, behave the way they do now, and will behave in the future - given the same kinds of historic or ongoing processes that change only quantitatively".

The paradigm of SD is based on the belief that 'continuous' is a valid description of 'discontinuous'. Fixed-policy models, with their unchanging and thus continuous decision-rules, are assumed to be good enough for description and prescription. However it is becoming evident that discontinuities should not be omitted from a model.

Some systems dynamicists believe that the catastrophe theory could in some way be adapted to SD. But this is the same kind of superficiality systems dynamicists claim econometricians are guilty of. Linstone (1980) expressed the same idea when he said: "A recent fashion in reductionism is the transfer of entire theories from one field to another (often fallaciously presented as an example of interdisciplinarity)".

The future is usually not the same as the present but there are two ways of solving this problem of environmental variety: by restricting environmental variety or by increasing system variety. Robustness is based on the first choice but vulnerability on the second choice. In RD, variable model structure increases system variety.

The O.R. approach and the classical system dynamics approach are opposing poles on a continuous spectrum when it concerns the use of future information. In O.R., it is customary to construct models which have a planning horizon from a few months to some years. Coyle (1977) did exactly that in a reported case-study but this is not a very common approach in SD.

The purpose of the planning horizon is to increase the quality of the first period decisions of the model. Then the model is updated with the ex-post information from the first period and solved again after moving the model forwards.

Here we will take a more general stand by assuming that, instead of moving the model forwards one period, it will be moved a time slice known as **action time** . Both the planning horizon and the action time are actually variables but are usually treated as constants. By using the planning horizon and the action time, optimization may be split into several time steps. This alternative is called **dynamic optimization** in order to distinguish it from **static optimization** where the splitting does not occur.

Each good piece of SD study proceeds during the interactive process of evolving model versions which results from recursive modelling efforts and from checking the quality of the model by simulation. Figure 12 describes the SD approach. "Explorative" means that the purpose of simulation is to find the right model. The accepted model version produces the solid line. The length of all the lines is the same, i.e. the time horizon of the study. Figure 12 could describe either ordinary simulation or static optimization.

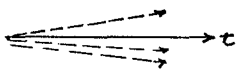

Figure 9. Simulation or static optimization

Figure 13 illustrates the use of the planning horizon and the action time in dynamic optimization.

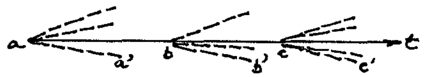

Figure 13. Dynamic optimization

Figure 13 describes a situation where the stage of **explorative simulation** occurred three times because the model was revised twice during the simulation. Action time stipulates the steps in **real time simulation** In figure 13, they are ab and bc. The length of the planning horizon are aa', bb' and cc'.

The model attempts to describe the true but unknown process behind some real world behavior. If the unknown process does not change and the quality of the model is high, the model needs no revision during the simulation. This assumption relates to all SD-modeling and to static optimization. In dynamic optimization, a model of a more modest nature can be used as the model can be readjusted.

Validity is a relative concept in SD as one must choose between competitive models and because validity can only be assessed relative to a particular purpose (Forrester & Senge, 1980). In RD, the purpose may be a choice between competing models during the real time simulation.

Time is one of the model resources and its aggregation depends on the problem under consideration. The time horizon should be a compromise between how fast the future is changing and how fast the system can adjust to that change.

When the time horizon is short, the reaction of the model to shocks should be fast. An interrupt-feature is thus required to facilitate new planning immediately after the disturbance has occurred.

The ideas I have just described are not new but they have now been made operational. The underlying concepts can be traced from Ashby (1960) who described Homeostasis as follows:

> Two systems of continuous variables (that we called 'environment' and 'reacting part') interact, so that a primary feedback (through complex sensory and motor channels) exists between them. Another feedback, working intermittently and at a much slower order of speed, goes from the environment to certain continuous variables which in their turn affect some step-mechanisms, the effect being that the step-mechanisms change value when and only when these variables pass outside given limits. The step-mechanisms affect the reacting part; by acting as parameters to it they determine how it shall react to the environment.

In modern words, Ashby believed that some stepwise-changing parameters control the controller and on the basis of intermittent information from the real world. What he did not say was that all parameter changes should be based on an estimate as to how well an overall objective has been fulfilled. Figure 14 relates Ashby's homeostasis to SD and to RD. The primary feedback loop is the basis for heuristic optimization. The intermittent link allows the use of decision parameters for structural adjustments.

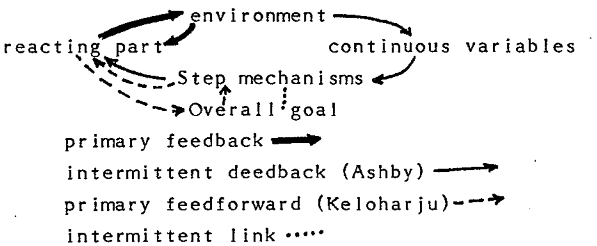

Figure 14. Ashby's Homeostasis revised

Synthesis has two aspects: **sequential** sampling and **parallel** sampling. Sequential sampling is based on the idea that problem description needs revision from time to time. Technically the problem is solved by dynamic optimization. In parallel sampling, problem description is revised at a specific point in time because different viewpoints bring new information.

4. New paradigm at work

Job-rotation is a common procedure in management apprenticeship. It aims to creating generalists from specialists by letting the specialist take different standpoints. In the same way, a better model may be received by changing the approach to the system that is being modeled.

Input, overall goal and output are the alternatives to choose from. Systems-rotation relates to a change from one choice to another and it is based on the **estimation-principle :**

> Inputs, overall goal and model are the basic elements of any system. If the modeler has two of them, the third one may be estimated. This procedure is single-move. The revised estimate of the same element results from reversing the approach. Instead of single-move, we now have double-move.

Figure 15 shows the three variations of single-moves.

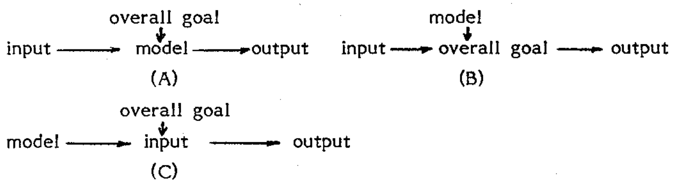

Figure 15. The single-moves

Two single-moves add up to a double-move. For example, the combination (C) + (A) revises the model:

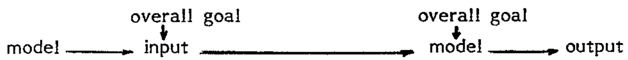

Figure 16. The example of double-move

I will now give an example of a single-move and a double-move.

Example 1.

In 1960, Bowman suggested that decision rules should be constructed for management via regression analysis from historical management decisions. Bowman's study was one of many methodological attempts to reformulate the Aggregate Production Planning problem in Management Science. This problem was later extended to cover other fuctional areas besides production (Damon & Schramm, 1972) as well as to disaggregate the production process (Hax, 1978). Morecroft (1979) studied a combination of Materials Requirements Planning and Aggregate Production Planning with a SD-model.

I showed above that conceptually RD is similar to The aggregate Production Planning model of Holt, Modigliani, Muth and Simon (The HMMS-study, 1960) was reformulated as a SD-model (Keloharju, 1982) from the cost function. It was accumulated over the run-length of two years and then minimized. The final values for inventory and workforce were fixed by using a penalty function. The penalty function was received from the known optimum solution (Taubert, 1968).

NOTE THE HMMS COST FUNCTION
A PCOST.K=K1*W.K+K2*(W.K-WO.K)*(W.K-WO.K)+K3*(P.KL-K4*W.K)*
X (P.KL-K4*W.K)+K5*P.KL-K6*W.K+K7*(I.K-K8)*(I.K-K8)
C K1=340
C K2=64.3
C K3=0.2
C K4=5.67
C K5=51.2
C K6=281
C K7=0.0825
C K8=320
L TCOST.K=TCOST.J+DT*PCOST.J
N TCOST=0
A TCOSM.K=TCOST.K+1E6*(109-W.K)*(109-W.K)+1E4*(455-I.K)*(455-I.K)

For systems-rotation, the overall goal, the inputs and the model have to be defined with parameters. The input consists of demand which will be created by a data generator with a linear and a cyclical component:

DEQ.K=CON+SLP*TIME.K-AMPL*SIN(6.283*TIME.K/PRD), where
DEQ = demand equation
CON = constant
SLP = slope
AMPL= amplitude
PRD = period

The equation has four parameters: CON, SLP, AMPL and PRD. Their values will be received as a byproduct of the curve fitting procedure. Instead of regression analysis, we use heuristic optimization to fit empirical demand data from the HMMS-study to the demand curve.

The demand equation D1 and the overall goal (minimization of the objective function, G1) generate the model, M1. The value of cumulative cost TCOST was 0.758E6.

After having used the model approach, we will now choose the approach of overall goal. Let us denote cost minimization, which was the overall goal in the HMMS-study with the symbol G2. Figure 17 shows schematically the essence of global sensitivity analysis.

D1
↓
M1 ——→ G2

Figure 17. The approach change from model to cost

The numerical values of the HMMS cost parameters were given above. They were changed by optimization and in such a way that the total original cost was repeatedly increased by 1%. This is a global approach because all parameter changes are interrelated.

A movable target value for the total cost TARG was defined as a function of the original total cost INIT. The absolute value of the deviation was then minimized to zero.

The construction of a new objective function DEVO is given below. INIT shows the value of the objective (cumulative costs) in the best model version found through transient hypothesis.

C INIT=0.758E6
C INCR=0.01
A TARG.K=(1+INCR)*INIT
A DEVO.K=MAX(TCOST.K-TARG.K,TARG.K-TCOST.K)

INIT = initial value of total cost TCOST
INCR = percentage increase in total cost
TARG = target value for total cost
DEVO = total cost deviation

By minimizing DEVO, the total cost is pushed into the upper boundary, defined by TARG. The value of INCR was increased repetitively by 0.01 from a terminal.

Figure 18 collects the new cost parameter values at regularly spaced checking points.

Model versions	C1	C2	C3	C4	C5	C6	C7
	Cost parameter						
0	340	64.3	0.2	5.67	51.2	281	0.0825
1	335	48.1	0.247	5.48	50.2	250	0.118
2	334	45.8	0.344	5.43	50.3	250	0.139
3	333	47.5	0.440	5.43	50.3	250	0.189
4	333	54.5	0.438	5.40	50.3	249	0.250
5	333	55.9	0.585	5.41	50.3	249	0.245
6	333	40.0	0.750	5.41	50.3	248	0.225
7	332	35.1	0.724	5.41	50.3	248	0.400

Fig.18. The cost parameter sensitivity

Figure 18 shows that there are three main types of cost parameter behavior: oscillatory (C2), convergent (C1,C4,C5,C6) and growing (C3,C7) in the reported eight cost models. An approximately stable cost parameter value indicates that sensitivity is related to the model structure. The magnitude of the relative change shows how sensitive the parameter is. The growth mode shows that the parameter is sensitive and is application dependent. The cost parameter C7, which summarizes the unit monetary value of all inventory items, is a good example of that mode. A change in the unit-price of the inventory items will always affect total costs.

A fluctuating cost parameter indicates that it is not important in the optimization process. Therefore some unexpected values might occur.

Global sensitivity analysis, in which all parameters are simultaneously changing, is a totally unexplored field. The purpose of the example above was to demonstrate the potentials of this approach.

Example 2.

In Part 2 of this paper I introduced two pure strategies (X and Y) of simplification when the purpose was to simplify the model structure. But model behavior depends on model structure. Therefore in 'behavior domain' there should be the corresponding pure strategies X' and Y'.

When systems dynamicists seek robust models, they actually want to minimize the maximum "regret" from bad model behavior.

Let us look at the SD approach more closely. It assumes that, in uncertainty, the real world behaves in a standard way. Step and sine functions usually represent the uncontrollable part of the real world. When the modeler adjusts his model on the basis of information received from those tests, he is minimizing the maximum future "regret". In the case of sine function, this is obvious because fluctuations are undesirable.

The same also concerns the use of step function although the argument is slightly different. Suppose that a step function describes a permanent increase in demand and that this situation is beneficial. If the firm reacts to this increase in a completely improper way, this causes the maximum regret. The purpose is to react in the right way and, by so doing, the firm minimizes the maximum regret.

Figure 19 shows how the strategies Y and Y' are of opposing nature when strategy Y maximizes simplicity "goodness" and strategy Y' minimizes behavioral "badness".

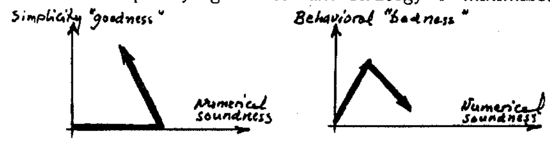

Figure 19. The comparison of strategies Y and Y'

In robusteness, an acceptable solution is attained through the worst solution. This statement emphasizes both the way of arriving at a robust solution and the quality of the solution. If the quality is less than perfect, the robustness approach leads to a vulnerable model instead of a robust model, which is the ultimate goal.

I will, therefore, call anti-robustness the approach where an acceptable solution is attained through the best solution. Simplification via strategy Y' is **anti-robustness.** Strategy X is also anti-robustness despite its contrary appearance. Instead of sequential sampling in the soundness-space, strategy X is based on parallel sampling. Let us now see how the double-move of Y' can be carried out in the demand-cost-model space. Figure 20 shows both steps schematically.

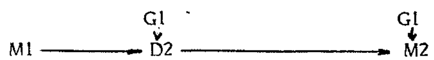

Figure 20. The modeling via double-move

So as to see what will happen we proceed as follows:

(a) The left of Fig. 20

A target value for the total cost acts as the upper boundary that is to be attained. The total cost will thus be increased. The absolute value of deviation between the total cost target and the initial total cost is reduced to zero in the optimization process. The procedure generates new values for demand parameters SLP,PRD and AMPL.

(b) The right of Figure 20

A new model is found by minimizing the total cost when demand changes from D1 to D2. This round-trip procedure is called **flip-flop optimization** in order to emphasize the reversible nature of stages (a) and (b) above.

(c) The new model M2 is tested with the old demand data D2 to compare models M1 and M2 and to see whether there has been an improvement or not.

Figure 21 summarizes stages (a), (b) and (c).

Stage	Objective function	Parameters to be optimized	Given parameters
(a)	DEVO	SLP, PRD, AMPL	Model parameters
(b)	TCOST	Model parameters	Demand D2
(c)	TCOST	Model parameters	Demand D1

Figure 21. A double-move from the technical standpoint

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