FROM A STATIC PICTURE TO A DYNAMIC PROBLEM DEFINITION

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ABSTRACT

Problem definition is the first and the most crucial stage in any System Dynamics study. A good and clearly defined problem is prerequisite to a good System Dynamics modeling. However, the way that a good dynamic problem is defined is subtle, is not well formulated and is not well taught. This paper presents a structured approach to dynamic problem definition that starts from a static picture of the real world and turns it into a dynamic problem. The paper argues that most people are familiar and capable to present static picture of the situation of a real world system. The paper uses such a familiar picture as a starting point to define a dynamic problem. The approach is applied to develop a problem definition for a railway company as an example.

INTRODUCTION

Any good system dynamics model should be based on a clear and well defined dynamic problem. That is the problem which sets an objective for the model and a base for making different decisions in the process of modeling. All decisions about the boundary and the endogenous variables, the relevant relationship between different variables, relevance, validity, and usefulness of the model should be based on the objective of the model and the objective itself is based on the dynamic problem at hand which demands answers to some clear questions. Without a well defined problem, a modeler does not have a clear objective for his efforts, he might do many different things without accomplishing any useful thing, he does not have a criteria to decide what to put into the model and what to put out of it, he does not know when the model is adequate and he could stop his modeling efforts, he does not have a criteria to know usefulness or validity of his model, his modeling efforts go nowhere.

But, in the real world, well defined dynamic problems do not exist on themselves that a modeler could pick them up and start a useful and goal seeking modeling process. Dynamic problem should be defined by the modeler. In fact, problem definition is a very important and crucial part of the modeling process that should be done by the modeler. What a modeler can usually start with is some real world difficulties. Difficulties are some bothering conditions, undesirable or unsatisfying situations that management or decision makers would like to change. But difficulties are not adequate base for the modeling process. The modeler should convert the difficulties into a dynamic problem. This conversion is usually difficult and subtle.

In teaching materials and the literature of system dynamics, there is not much about problem definition process. Richardson and Pugh (1981), Randers (1980), Andersen and Richardson (1980), and Richmond and et. al. (1987) identify the problem definition as one important step in the modeling process. However, with the exception of Richardson and Pugh (1981) and Randers (1980), the author is not aware of any literature that give some hints on how a dynamic problem should be defined. Subtleness of the problem definition process and lack of literature on this subject have made teaching of problem definition very difficult. In fact, as far as the author knows, in System Dynamic courses very little, if any, is taught about problem definition. Students do not learn how to define a dynamic problem and as a result they do not learn how to take the first crucial step in System Dynamics modeling. If students do not learn how to take the first step successfully and to define a clear problem and to lay down a good basis for their modeling efforts, then they can not succeed in their System Dynamics modeling effort. System Dynamics teaching can not train good modelers. If good modelers can not be trained, then the great potential of System Dynamics can not be utilized to help our societies to become a better place to live and the field itself does not grow as much as it should.

This paper is only a step towards giving more structure to the process of problem definition. The next section explains the concepts of difficulties, problem definitions, and dynamic hypothesis. Then, Section 3 of the paper discusses the static picture of the system as an easier and more common way of looking at a system. Section 4 of the paper presents an approach for defining a dynamic problem from a more understandable and familiar static picture of the system. Section 5 explains an example for using the approach presented in Section 4 to define a dynamic problem for a railway company. Finally, conclusion comes as the last section of this paper.

PROBELM DEFINITION AND DYNAMIC HYPOTHESIS

Any scientific study begins with problem definition and hypothesis formulation. A System Dynamics study as a scientific enquiry is not an exception. The first step of any System Study a problem should be defined and a hypothesis should be provided with relation to that problem. Problem should be defined by the analyst starting from the difficulties which exist and can be felt and identified in the real world. This section will explain briefly three concepts of difficulty, problem definition, and dynamic hypothesis.

Difficulty: Difficulty is some inconvenient or bothering conditions that people face. Difficulty is something that felt and described easily by those who are in touch with it. In an economy, inflation, unemployment, trade and budget deficits are difficulties that when exist governments and people can easily feel mention. In a company, low quality, losses, high turn over in labor force, low capacity utilization, and loss of market share are example of difficulties. While it is easy to observe the difficulties, it is not easy to explain why they exist and what can be done to cure them. Problem definition is start of a process to provide explanation and recommendation.

Problem Definition: A very basic prior assumption in System Dynamics is that the world is dynamic. In the dynamic world the conditions of the real world is changing over time. The real world conditions of interest can be observed by variables representing those conditions. Variables such as market share, rate of return on investment, number of employees, current ratio, and inventory level in a company are among variables that represent the conditions of a company. The changes in the conditions of the dynamic world can be shown with the variation over time of the variables presenting those conditions.

People are concerned about the changes of the real world around them. The desired directions of changes in the real world conditions might depend on the view point of the persons who set those directions. But no matter what view points one takes, changes of the real world's conditions are not always in the desired directions. In order to make the world to change in the desired directions, there are two major related questions which be considered. First, why the conditions of the world are changing in the way that they do. Second, what can be done to change the direction of changes to desired directions. These are the two major general questions that any system dynamics study should address. Problem definition and hypothesis formulation in system dynamics are actually elaboration on these two questions for a specific situation.

A System Dynamics problem is definition by drawing and showing the actual or historical variation of important variables of concern over time. Such changes over time is usually called the reference mode for the dynamic study. The first challenge in a system dynamic study is to discover a system structure related to the real world and put it into a dynamic world which can generate the reference mode. Such structure with the causal relationship between its elements provide an explanation for the changes of concerned that we observe in the real world and in fact would be an answer to the first question stated above. In problem definition, the desired changes or behavior also might be drawn over time and the question can raised that how such desired behavior can be reached. The second challenge in any system dynamic study is to discover and propose what should be done to create the desired behavior in the real world using the dynamic model .

In System Dynamics, problem definition and dynamic hypothesis are very strongly related to each other and should come together. A problem definition is not complete unless it comes with a related hypothesis.

Dynamic Hypothesis: A dynamic hypothesis provides a preliminary explanation of the reasons that why the reference mode occur in the real world. This explanation should have some qualification which is dictated by the founding principle of System Dynamics or the feedback principle. This founding principle states that the conditions of a system lead to decisions (made either by human or the nature), the decisions cause actions which in turn change the conditions. Dynamic hypothesis or explanation of changes should be based on this circular causality which is the founding base of system dynamics. As one try to formulate a dynamic hypothesis to explain the changes of the variables indicating the real world changes, some new variables might appear in the explanation. If one can find historical data on the new variables, one can add the changes of those variable over time to the reference mode.

If the dynamic hypothesis is stated based on the feedback principles, it could be a basis for drawing causal loop diagrams to build a model. In fact the hypothesis has a dynamic nature and is appropriate as a basis for a dynamic model only if it includes feedback loops and could lead to a causal loop diagrams. Of course the initial hypothesis might not be correct or complete. In fact one of the major strength of system dynamics approach is that during the modeling process the initial hypothesis is corrected and enriched and through that process the modeler increases it's understanding and knowledge about the problem at hands.

STATIC PICTURE OF THE SYSTEM AS A STARTING POINT

People are usually more familiar with static picture. It is usually easier to present and discuss the conditions and situation of a system at a point of time rather than discussing the changes over time. Problem definition in System Dynamics can start from such a static picture at a point of time. In such a picture, important variables which show the conditions of concern at a point of time or system's performance during a single period like a year are presented. In order to make the presentation of the conditions and performance more meaningful, if possible, one should add some reference values which can make the judgment about the situation easier.

As an example, Table 1 shows a static picture of a rail road company in 1988. The important variables have been chosen to present the capacity utilization of the company in it's major facilities. Table 1 is a static picture that shows capacity utilization in major facilities of the company was very low in 1988. Such low performance resulted to annual loss in the company. Table 2, as another static picture, shows the summary of income statement of the company in 1988.

Neither capacity utilization nor financial performance of the company in 1988 was desired or appropriate. The above performance was under condition that demand for transportation was higher than supply and there were demand for what ever transportation services the rail road could provide within it's capacity limits in 1988.

The above static picture shows some difficulties at some point of time. These difficulties have been developed over time and have not become into being momentarily and without any connections to the previous conditions of the company. These difficulties are the result of interaction between some elements within and outside the rail road company. Problem definition and dynamic hypothesis should connect the above static picture to continues previous changes with reasonable explanation for the reason of the changes.

FROM STATIC PICTURE TO A DYNAMIC PROBLEM

To develop a dynamic problem from the static picture, the following steps are proposed.

1. Information Gathering: The first step to develop a dynamic problem is to gather information about the reasons and explanations for the existence of the difficulties presented in the static picture. There are two important sources for such information: written information and people working in the system. Written information includes any theoretical or practical documents which provides explanation about how the difficulties of concerned in the specific situation of interest or similar situations have developed. This information which is gathered through this literature survey could be very valuable to enrich the problem definition and dynamic hypothesis and is also very

Table 1: Capacity Utilization in The Rail Road Company

Description	Capacity Unit	Capacity	Performance	% of Capacity Utilization
Locomotives	Million Ton-Kilometer	168	34	20%
Freight Wagon	10E9 Ton-Kilometer	118	8	%7
Passenger Wagon	Million Person-Kilometer	19000	4661	21%
Rail Roads	10E9 Ton-Kilometer	36.5	12.6	34.5%
Locomotive Maintenance-Shop	No. of Overhaul Per Month	50	25	50%
Wagon Maintenance-	No. of Overhaul Per Month	500	315	62%

Table 2: The Summary of Income Statement of The Rail Road Company in 1988 (Million Rials)

Total Revenues		31751
Freight Revenues	19337	
Passenger Revenues	7112	
Other Income	5302	
Operation Cost		50591
Salaries	31869	
Depreciation	7041	
Parts	2863	
fuel	1134	
Other Expenses	7684	
Operating Profit (Loss)		(18840)

useful to connect the study to the literature. Unfortunately usually the literature does not provide dynamic explanation based on feedback principle. Explanation which exists in the literature form parts and pieces of a comprehensive system based explanation which should be developed by the researcher. However, the pieces gathered from the literature when combined with a system dynamics view point could create a good preliminary dynamic hypothesis.

The second source of information are managers and decision makers who are familiar with the situation and are managing it. These people have some ideas about the reasons of the difficulties. Interviews and discussion with these people provides valuable information. Of each person of this group might see and present some parts and parcels of the reasons. But theses first hand and useful partial information could be put together by a system dynamics view point and create a clear problem definition and a rich and deep dynamic hypothesis.

2. Draw Changes of Important Variables Over Time: Based on the information that have been gathered in the previous step, for each variable in the static picture some important related variables should be identified. Then, one should try to gather historical data about the important variables and draw their changes over time. The related variables which are drawn over time should be helpful to explain the reason for difficulty presented by the main variables. To identify such related variables, one has to ask questions which are helpful to find out the reasons for the difficulty. To ask such questions, one has to make himself familiar with the system and it's major elements. Familiarity with the system is obtained in the previous step, and can be extended as one tries to explain the reasons and sometimes has to go back to the previous step and gather more information about the system.

3. Provide A Dynamic Hypothesis: Based on the information gathered in the first step, a dynamic hypothesis should be formulated to explain the reasons of the changes in the variables drawn in the previous step. As was mentioned before, the dynamic hypothesis should be based on the feedback principles and System Dynamic view points. Again in this stage one might have to go back to step 1 to gather more information or go back to step 2 to draw some more variables in order to make the dynamic hypothesis more plausible.

4. Draw a Causal Loop Diagrams: Finally, the dynamic hypothesis that was developed in the previous step is used to draw causal loop diagrams. This is a very important step which firstly tests the comprehensiveness and the dynamic nature of the hypothesis. If the dynamic hypothesis is not stated properly, then causal relationships which are drawn based on that hypothesis would not form closed loops. If that the case then one should go back to the step 3 and correct or complete the hypothesis. Secondly, in the process of drawing causal loop diagrams, usually new causal relations and new causal loops which were not considered in the dynamic hypothesis come into mind which could enrich the preliminary dynamic hypothesis. Before including this new causal relationships one can go back to the information gathering step and look for evidence to support the new relationships and then add those relation to the dynamic hypothesis and also to the causal loop diagrams.

AN EXAMPLE FOR PROBLEM DEFINITION

In this section, as an example, a problem definition and dynamic hypothesis is presented in relation to the static picture discussed in section 3 of the paper. In this example, information gathering step was done by reading available materials that describe the rail ways company and provide some analysis about the difficulties that the company is facing. In addition, interviews and discussion with managers of the company provided useful information.

Based on the information gathered, some variables related or useful to explain low capacity utilization of locomotives were identified. Some of those related variables are total number of locomotives, locomotives under maintenance, locomotives in service, number of locomotives overhauled each year, and the average millage of each locomotive per year. Changes in these variables are drawn in Figures 1 and 2. In addition to the variables directly related to locomotives performances, many other variables were drawn which were useful to explain the development of the difficulties in the company. However, not all the graphs of those variables are presented in this paper. Only changes of some variables related to rails which are also useful to explain

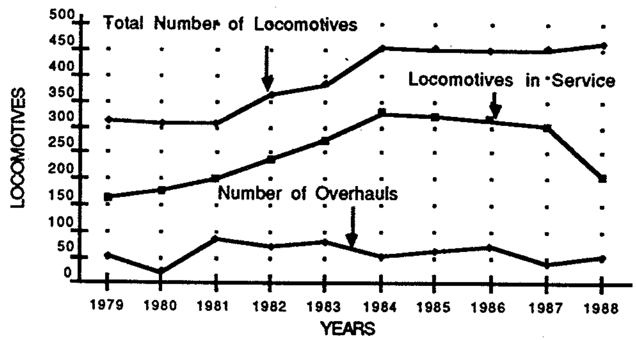

Figure 1: Changes in Locomotives and Number of Overhauls Per Year.

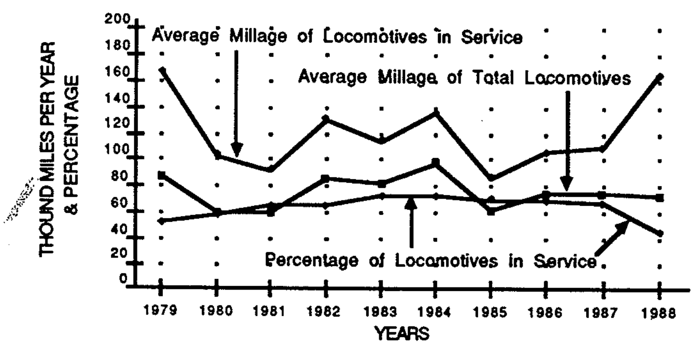

Figure 2: Average Annual Millage and Percentage of Locomotives in Service

low performance of the locomotives are presented in Figures 4 and 5. Figures 1, 2, 4, and 5 are used to define the problem.

In this example, the dynamic hypothesis starts with following explanation related to Figures 1 and 2. Locomotives in service are the moving force in the rail road. As is shown in Figure 1, total number of locomotives increased from 235 to 327 during 1982 to 1988. However, number of locomotives in service in 1988 is 148 which is less than 166 locomotives in service in 1982. As total number of locomotives increases, so does the number which need overhaul services. However, as shown in

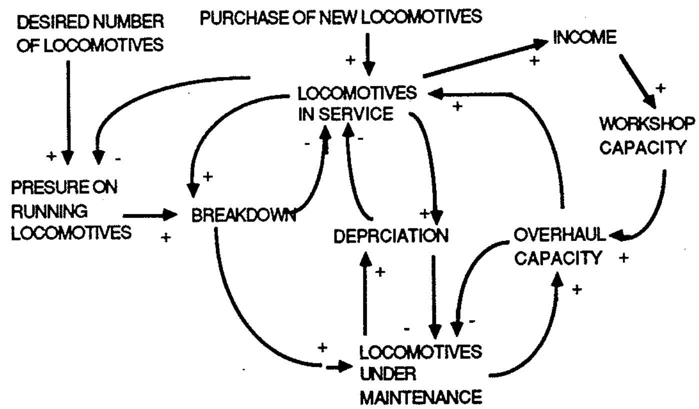

Figure 3: Causal Loop Diagram Related to the Dynamic Hypothesis.

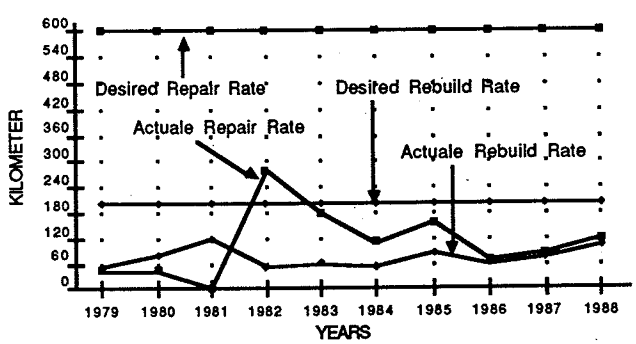

Figure 4: Rate of Repair and Rebuilt of Rail Roads.

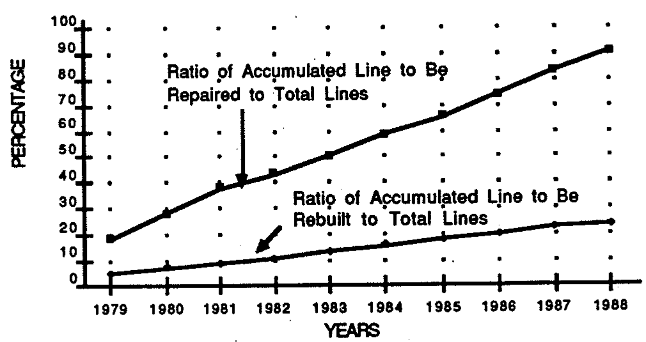

Figure 5: Ratio of Accumulated Lines to Be Repaired and Rebuilt to Total Lines

decreases. Decline of company income would decrease the capacity of the company to

Figure 1, the number of locomotives which went through overhaul services not only did not increase, but to some extent the number of overhaul shows a decreasing trend because of shortage of maintenance capacity. Due to inadequate maintenance capacity, locomotives remain out of service and under maintenance for a longer period of time. As a result locomotives in service drops after 1984, as it is shown in Figure 1. Decline of locomotives in service aggravate shortages of locomotives and increases pressures on the running locomotives and causes delay in timely services. As a result, breakdown of locomotives increases and locomotives in service declines more rapidly, as is shown in Figure 1 for the period of 1984 to 1988.

Decline of locomotives in service decreases company income. Decline of company income decreases the workshop capacity or capability of the company to do overhaul services. As the result the overall performance of the total locomotives declines and in fact decreases the capacity utilization of the locomotives in the company.

Base on the above hypothesis one can draw a causal loops diagram shown in Figure 3. Causal relationships in Figure 3 will a basis for model development in the later stages of modeling effort.

Low capacity utilization is not only due to the imbalance between growth of number of locomotives and capacity of maintenance workshop. The quality of rail roads which affects the velocity of locomotives on the rails is another determinant of capacity utilization of locomotives. If quality of rails deteriorate, then locomotives can not move as fast as they should and as a result their capacity utilization would drop. When changes in the rails quality were investigated, it became clear that the quality is dropping.

Total length of the rail roads is 6000 kilometer. In order to keep the rails in good shape, they should be repaired every other ten years and should be rebuilt every other thirty years. Figures 4 and 5 show some important variables related to the quality of the rail roads. In Figure 4 the desired as well as actual repair rate and rebuild rate are shown. While every year 600 kilometers should be repaired, the actual rate during most of the period has been less than 200 kilometers. And while every year 200 kilometers should be rebuilt, the actual rate of rebuild is much less than the desired rate. Every year that actual rate of rebuild and repair are less than those desired, then the difference is accumulated and accumulated lines which have not been repaired and rebuilt on time will increase. If one assumes that before 1979 all the rebuild and repair works were completely done, then due to inadequate repair and rebuild work after 1979, the ratios of accumulated lines to be rebuilt and repaired to total lines increase as is shown in Figures 5. Accumulated lines to be rebuild are old lines with low quality. Accumulated lines to be repaired are mediocre lines with average quality. In fact in year 1988, 92 percent of lines should be repaired and have average quality and 23 percent should be rebuilt and are old lines with low quality. Such high ratios indicate that the rails are not in a good shape and their quality is low. On low quality rails, locomotive could not go as fast as they should. Low velocity would decrease the capacity utilization of the locomotives and income of the company. As income decreases, so does the capability of the company to service the lines.

Low quality of rails influences the capacity utilization of locomotives in some other ways too. When quality of rails deteriorate, locomotives break down rises and decreases the number of locomotives in service. When locomotives in service decreases, then capacity utilization of locomotives drops and income of the company service the rail lines and as a result rate of rebuild and rate of repair decline.

The above dynamic hypothesis about changes in variables related to rails is basis to draw a causal loop diagram for shown in Figure 6.

One can continue to complete the definition of a dynamic problem for the rail ways company by drawing more variables related to the variables presented in the static picture in Section 3 and expand the dynamic hypothesis and related causal loop diagrams. Extension of the graphs and dynamic hypothesis should continue to the point that the modeler feels all important and relevant factors and mechanisms responsible for the difficulties presented in the static picture are considered. At that point the problem definition and the dynamic hypothesis is developed enough to start model formulation. At the problem definition and hypothesis formulation stage, it is also useful to think of the desired behavior and possible policies that could create such desired behavior. Hypothetical policy formulation could help the modeler to check if the necessary elements are included in the model for policy design. Of course as was mentioned before, problem definition, hypothesis formulation, and causal loop diagraming are all the beginning of the modeling process. As modeling goes on, the modeler and the managers and decision makers who are involved in the process would improve their understanding of the problem and would correct and enrich their hypothesis and their understanding of the causes of the difficulties and proper policies to overcome the difficulties.

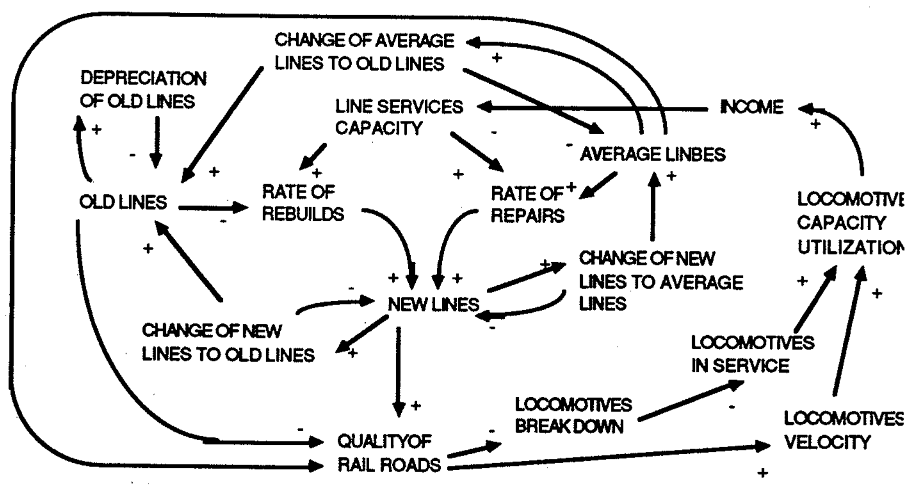

Figure 6: Causal Loops Diagram Related to Rail Roads.

Reference:

- Andersen D., Richarson G., 1980, Toward a Pedagogy of System Dynamics, TIMS Studies in Management Vol. 14.
- Randers, 1980, Elements of The System Dynamics Modeling, MIT Press.
- Richardson G., Pugh, 1981, Introduction to System Dynamics Modeling, MIT Press.