MODERN AND SYSTEMS-ORIENTED RESEARCH METHODOLOGY

M. Bunjamin*

Abstract MODERN AND SYSTEMS-ORIENTED RESEARCH METHODOLOGY This paper is to report the results of literature studies on the latest development of systems-oriented research methodology. Scientific communities' effort to modernize research methodology is based on the fact that research is no longer of academic interest only, but it has become an integral part of modern business practices that highly influenced by market dynamics. Consequently, there is a strong pressure on the research institutions that they should be able to achieve and produce concrete research results effectively, efficiently, and productively, as well as meeting rapidly change market demand.

Abstrak METODOLOGI PENELITIAN MODERN BERWAWASAN SISTEM Tulisan ini melaporkan hasil studi literatur tentang perkembangan metodologi penelitian modem berwawasan sistem. Maksud para peneliti untuk memutakhirkan metodologi penelitian ialah karena sekarang penelitian bukan memenuhi selera akademik saja, tetapi sudah menjadi bagian integral yang tak terpisahkan dari kegiatan bisnis modem, sehingga sangat dipengaruhi oleh dinamika pasar. Akibatnya, institusi penelitian sangat dituntut untuk mampu berprestasi dan mampu menghasilkan karya-karya penelitian nyata secara efektif, efisien, dan produktif, sekaligus mampu memenuhi permintaan pasar yang cepat berubah.

INTRODUCTION

It is well known that a large scale research should be managed properly to achieve maximum outputs with minimum inputs, and this is done mainly thru planning, implementing, and controlling. Planning is determining *where we are now*, *where we want to be*, and *how to get there* (Figurel). Implementing is *the action of actually getting there*, while controlling is *how to measure our progress* in our attempt to get there. In research activities, *research methodology* is one of the most important methods of *how to get there*. It is a fact that research activities all over the world are suffering from shrinking research funds and at the same time are under pressure from rising expectations for producing concrete research results. In the case of government's research institutes, the high expectations come from the tax-payer, while for the research units belonging to the private industries, the high expectations may come from customers and share holders.

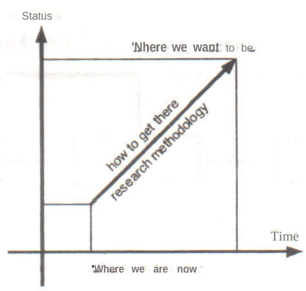

Figure 1. Concept of Planning

* former senior lecturer, Education and Training Center, Batan

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Research is an attempt to *collect* as much as possible *new data/information/... facts* regarding our immediate environment in particular, our world, its contents, and the universe in general. The purpose of this is to meet our scientific curiosity as well as to be used to develop new technologies for human purposes such as food, housing, energy, transportation, communication, etc. That is why there are three stages of research activities, namely a) basic research, which deals with exploration, discovery, and explanation activities, b) applied research which deals with finding scientific feasibility, innovation, and invention, and c) developmental research which is trying to find technical feasibility, economic feasibility and construction of prototypes for testing purposes, that may lead to production and marketing.

Research methodology is a collection of *research principles, practices and procedures* accumulated throughout the history of science and has been adopted by the scientific community. By applying proper research methodology, the researchers can be sure that their research activities are done properly and the conclusions are drawn correctly so that it can be checked / rechecked / reproduced and understood anywhere, anytime by anybody who are interested.

A *system* is a collection of *components / elements / parts* which are interdependent and interacting with each other and cooperating sinergistically to achieve the system's goal. In general, the parts of a system still have the structure of a system, so that they are called subsystems. The system itself is part of a bigger system called *supersystem.* The main goal of a system is to survive.

The fact that there are interdependencies and interactions among the subsystems in a system, and therefore among the systems in a supersystem as well, shows that:

I) The subsystems/systems are in general *open systems,* meaning that they receive/need *inputs* from other subsystems/systems and produce *outputs* to other subsystems/systems. Inputs and outputs may be *information and/or matter and/or energy,* and between input and output there is a *cause--effect* relationship called the systems *mathematical model.* In order for the subsystems of a system able to cooperate synergistically, every subsystem must make sure that its outputs meet the system standards in quality and quantity. Otherwise, the survival of the subsystems will be in danger, and, on top of that, the survival of the whole system will be in jeopardy as well.

2) From the fact that subsystems/systems are open, there must exist a *communication* subsystem that enable *information/matter/ energy traffic* among the subsystems/ systems. The communication subsystem consists of *feedback* and *feedforward* subsystems. The feedback will enable the subsystems to know (= leaming [rom the past) whether their outputs are acceptable by the system or not. The feedforward will enable the subsystem to predict what will be the future needs of the system.

3) Another property that can be concluded from the openness of a system is that every system must be *adaptive* to the dynamics of the supersystem where it belongs. Without this adaptation capability, a system will soon die out and be replaced by another -- more adaptive -- system.

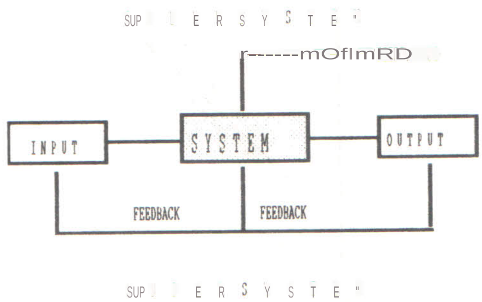

Figure 2. A concept on system

A *systems-oriented research methodology* means that there is an awareness on the part of the researchers that *the objects they are investigating are systems* with the above-mentioned properties of systems in general. This implies that when a researcher is investigating any object/system, three different problems come up, namely:

1) when an input/stimulus is given to the system, what will be its response/ output, and when there are many inputs given with many outputs produced by the system, what is the mathematical relationship between inputs and outputs?
2) what are the parts/components of the system, and how do they interact with each other?
3) how does the system interact with its surrounding?

There are two aspects for every system, namely space-dimensional and time-dimensional aspects. The space-dimensional aspect come from the fact that there are interdependencies and interactions among systems, while the time-dimensional aspect come from the fact that all systems are dynamic (= dynamical systems), meaning that they change with time. Geologists can tell us that big mountains, that look static to most of us, are actually moving, albeit slowly.

The researchers themselves are also systems, who also have the space- and time-dimensional aspects. The space-dimensional aspect is popularly known as *think globally and act locally,* while the time-dimensional aspect is known as *think far ahead and act now.*

The following diagram illustrates the above-mentioned questions whose answers must be found by the researchers as part of their investigation.

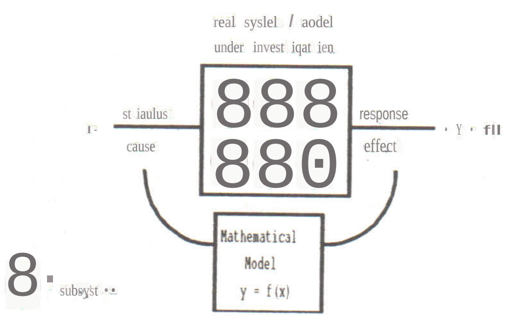

Figure 3. Ilustration on typical investigation

Modern research methodology means a methodology which is adapted to the rapidly changing demands and expectations of the dynamic market, both local and global, as we are approaching the 21st century. The biggest demand imposed to the research units all over the world is that research must be done successfully, cheaply, and fast. This is very important if the company where the research unit belongs is going to survive in the local, regional, and global competition through market-pull and technology-push. One way to meet this demand is -- based on the experience of the advanced industrialized countries -- to support research activities by using as much modeling & simulation as possible. This is due to the fact that experiments are more expensive to run than simulation, and simulation is relatively cheaper because computers are nowadays cheap, and yet very powerful. Even when the research will be done experimentally, it is important to precede it by runing a computer simulation to reduce trial & error in the experiments. thereby reducing costs and duration of experiments.

ANALYSIS, SYNTHESIS, AND CONTROL PROBLEMS

If we look at scientific problems from the *systems-approach* point of view, while realizing that:

a. the object under investigation is a system consisting of many interacting subsystems,
b. systems receives inputs and produces outputs,
c. there is a cause - effect relationship between inputs and outputs,

then we may classify these problems into three groups as follows.

1. *Analysis problems* (direct problems / forward problems)

The first time a researcher is facing an unknown system, one way to start his research to learn the system's properties/ behavior is by *giving the system several stimuli* (= inputs) and *observe the system's responses* (=outputs). In this case he considers -- at least for the time being -- the system as a black-box, meaning that he ignores what is inside the system and what is going on there. Therefore he is using the holistic principle. These kinds of system problems are called analysis problems, and they belong to the direct or forward problems. In this kind of research he/she should be able to find the relationship, usually a mathematical model, between inputs and outputs of the system through experiments by observing the variation of outputs as a function of the varying inputs. The mathematical model found this way is always an algebraic equation, the simplest and the most popular of which is the linear equation $y = a + bx$, where the parameters a and b are found with the help of least squares method. Of course non-linear equations are also used, such as polynomials or exponential functions, as well as 3-D surfaces. Composite curves are also used for representing complex data. The physicists and engineers call this procedure curve-fitting or surface-fitting, while the statisticians call it regression analysis. When the model is found, the researcher actually have entered the second kind of systems' problem, namely the modeling problem to be discussed below. The schematic diagram of the analysis problem is as follows.

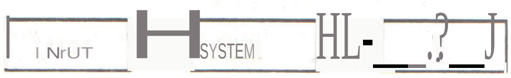

Figure 4. Schematic diagram of analysis problems

2. *Synthesis / modeling / design problems* (inverse problems)

At this stage of investigation, the researcher is no longer satisfied with the holistic principle, and he starts to wonder: *what are the subsystems making up the system as a whole, and how are they interacting with each other?* This means that he is now using the reducsionistic principle, that says: to understand the system's properties as a whole, the researcher must first understand the properties of the individual subsystems of the system and the interactions among them. These kinds of problems are called synthesis problems. After the researcher break the system into its parts and understand its mutual relationships, usually through a series of experiments, he may be able to deduce its mathematical model from these internal relationships, plus some mathematical postulates. The model obtained this way are usually in the form of differential equations, either ordinary or partial, either single or a system of differential equations. In engineering design, this problem is precisely the design stage of the entire engineering problem, which explains the name: design problems. Problems belonging to this group are called inverse problems.

The schematic diagram of the synthesis / modeling / design problem is as follows.

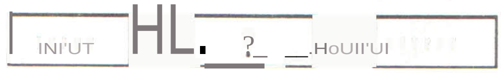

Figure 5. Schematic diagram of synthesis problems

3. *Control/instrumentation problems* (inverse problems)

At this stage of research it is assumed that to a certain extent we know the system and also the cause-effect relationship between input-output (usually a mathematical model). The question to be answered in this research is: *what kind of input should be given to the system so that it will produce the desired output?* That is why these kinds of problems are called control problems, because in many problems we are facing, we want to be able to control the output of a system to our desires by manipulating the input. When the system under investigation is a man-made system or machines, then the control problem is also called instrumentation problem, because we usually control modem machines using electromechanical or electronic instrumentation. Problems belonging to this group are also called inverse problems.

The schematic diagram of the control or instrumentation problem is as follows.

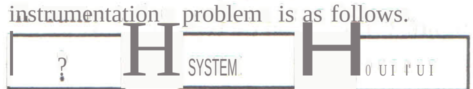

Figure 6. Schematic diagram of control problems

THE PRINCIPLE OF "SEEING IS BELIEVING" AND THE INVERSE PROBLEM

When an agricultural engineering student got a lecture from a professor, telling that a certain kind of fertilizer can increase rice yield, this is a new, but temporarily unproven, knowledge for the student. The truth of this knowledge will be proven when the student saw with his own eyes the cause-effect relationship between applying the fertilizer (=mput=cause) and the resulting increase in yield (=output=effect). of rice. This is an example of the principle of "seeing is oelieving." Of course, for a scientist, believing through seeing alone is not enough, and he must do the thinking or analyzing in order to understand the reasoning behind what he saw.

In many other cases, however, the researcher saw only the effect (=output) with no ability to see the cause (=input). For instance, when Roentgen discovered the X-rays many years ago, he saw only a blackened film without the ability to see the X-ray itself. But with the reasoning that there can be no effect without a cause, the presence of the X-ray was deduced. This belongs to the control problem. In the same manner, the scientists were able to prove the existence of protons, electrons, positrons, neutrons, molecules, DNA, genes, etc., without ever seeing them directly (Figure 7).

THE ROLE OF MODELS IN RESEARCH

A model is an approximation to reality, either in appearance or in some properties, or both. When a doctor has just found a new drug for a certain human desease, for example, he will not take the risk of directly testing the drug to a patient. Instead, it will be tested first to an animal, and if it is OK for the animal, it will most likely be OK for humans. In this case the doctor has chosen a chimpansee as the human model, knowing that chimpansees and humans have many similar physiological properties. In this example, the doctor as a researcher was using a physical model that has a physical similarities. Physical models are used by students and researchers in experimental studies or research, mostly to prove or disprove hypotheses.

Another model widely used by modern researchers are mathematical models, in tile form of algebraic or differential equations. With the aid of analytical or computational solutions on modem computers, researchers are doing experiments, better known as simulations, on mathematical models.In research projects dealing with complex and / or dangerous technical problems such as aircraft, spacecraft, nuclear, off-shore drilling, or world-wide communication network, the use of computer modeling & simulation is a must to reduce experimental costs.

DEDUCTIVE AND INDUCTIVE REASONING IN RESEARCH

When a researcher is doing an agricultural experiment on a piece of soil, for instance, and later on he draws a conclusion from the experimental data, can he expects that the same conclusion can be drawn from a similar experiment on any other soil? This kind of question, when the researcher -- backed up by a good argumentation -- can answer affirmatively, is called an inductive reasonning. This reasoning tries to generalize the results that was found locally.

The opposite of the inductive reasoning is tile deductive reasoning, which is a specialization of a general result to a particular case. Many results proven from mathematical laws are applied everywhere, because everyone knows that mathematical laws are everywhere valid.

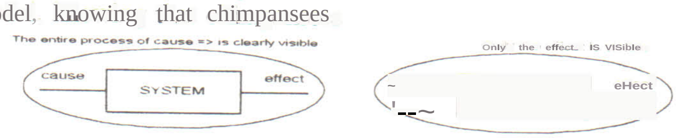

Figure 7. I1ustration on the relationship between cause and effect

RESEARCH THROUGH THEORY, EXPERIMENTS, AND COMPUTER SIMULA nONS

Since the old days of science to about the end of World War ll, traditional science were backed up by theory and experiments. Theories were used to explain (by analyzing is understanding) some phenomena observed in an experiment, while experiments are used to prove (by seeing is believing) what were hypothesized by theory. Theories were usually backed up by mathematical models which traditionally were solved analytically, while experiments were backed up by a good instrumentation system. Data accumulated from experiments were analyzed using statistical techniques such as regression analysis.

Since the end of World War II, a new way to approach science & technology opened up, namely through computer modeling & simulation. It turned out that the three scientific methods, namely theory, experiment, and simulation, were able to support each other, because each has its own weaknesses, but also its strengths. Modeling and simulation is especially useful for predictions and optimizations. Use of modeling & simulation prior to experimentation will enable researchers to reduce experimental costs by minimizing trial & error. Of course, of the three scientific methods, the final judge of truth is experiments, because only experiments can produce tangible results that can proceed directly to technology for market consumption.

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