A Holistic Model for Enterprise Development (II)

Hong Li
Water-Logic, Inc., Phone: 614-296-7644, Fax: 866-206-9568, Email: hong@water-logic.com
Shelby Laurents
Fluor Corporation, Email: shelby.laurents@fluor.com

Abstract: This is the second one in a series of articles on applications of Robert Rosen's M-R model in the study of enterprise development with Purdue Enterprise Reference Architecture (PERA). Mathematical discussions further explore the difference between the machine model and the organic model by following Rosen's definition in the context of enterprise development. The inherent infinity associated with the machine model facing a changing environment is revealed. To become Rosennean organic is the right choice for enterprises to be strategically ready for proactive strategic management. Rich perspectives represented by the holistic model are discussed. It is shown that the organic potentials can only be grown from organizational relations between management and operations.

Keywords: Enterprise Engineering, Systems Engineering, Relational Model, Complexity Theory, Enterprise Reference Architecture, PERA (Purdue Enterprise Reference Architecture), Systems Science

1. Introduction

In the previous article [Li, 2005], the entailment homology [von Bertalanffy, 1969, pp. 80 – 86] between PERA and Rosen's M-R model was identified. Discussions based on Rosen's model further explained why PERA offered a synthetic device that was able to help enterprise development follow either machine models, or organic models, or something in between. The empirical model of PERA full life cycle and the theoretical M-R model of Rosen share the following important considerations:

- They both emphasize the importance of the inherent purpose of the complex system in question. In terms of Aristotelian-Rosennean (A-R) entailment, it is the final cause that represents the purpose. In the case of enterprise development, it is the internality, instead of externality, of the final cause that typically differentiates organic organizations from machine organizations.
- They both rely on the necessary relational considerations as a means of holistic abstraction to capture the whole picture of complex systems. Where Rashevsky and Rosen termed as keeping the organization as a whole and throwing away all physical or material concerns, PERA insists that it is "What" to do, instead of "How" to do, that must be considered in the early phases of enterprise life cycles before specifications of material implementation.
- They both recognize the existence of non-computability in the subject systems in question. While Rosen pointed out many times that every M-R model is non-computable [Rosen, 1991, and 2000], PERA identifies the irreplaceable place of human and organizational development for enterprises. It is imperative that technical decisions on enterprise implementations be dependent of human and organizational considerations during enterprise development in general.

It is these considerations that have led PERA to break out traditional boundary of engineering practice. It is also these considerations that enable PERA develop organic enterprises. In a sense, an organic enterprise is one that has inner capability of strategic improvement and innovation, i.e. proactive self-adaptation to unforeseen influence for growth – as to all living things. A machine organization is one that strategically can only be altered by outside intervention or externally preplanned adaptation.

In terms of Rosen's M-R model, PERA model of full life cycle offers two important organic potentials, repair and replicate, that have been largely ignored by many other enterprise reference architectures. To become an organic enterprise, which is capable of self-sustaining and self-evolving as defined by Rosen in his M-R model, the three bio-functions, metabolic, repair, and replicate, must grow and evolve as a whole. The machine model then can be considered as a special simplification of the organic model. Because of the lack of proper internal orientation, enterprises that merely follow the machine model may only have limited flexibility.

In order to introduce Rosen's model into the field of enterprise development, the previous article was focused on a single enterprise life cycle and its development program. It compared between approaches

that follow the machine model and that follow the organic model to expose the otherwise hidden entailment patterns embedded in the life cycle defined by PERA. However, the purpose of this study is more than justification between theories from different background. It is more important to explore practical guidelines and answer key questions once the basic concept of organic enterprise development is redefined.

Although in the previous article, Rosen's Abstract Block Diagram (ABD) was applied as a basic graphic tool to help the presentation of entailment patterns, there are still more details about the entailment features that cannot be explicitly illustrated by the graphical language. These features however play vital roles in characterizing enterprise development. Based on the concepts from the first article as shown in Figure 1, this article will further present mathematically these details of Rosen's M-R model[1] in the context of enterprise development so that it will be possible to explore more Rosennean organic properties, particularly those of replicate function that are invisible to conventional analytical tools. The three bio-functions will be first discussed individually and then associated together in the M-R model.

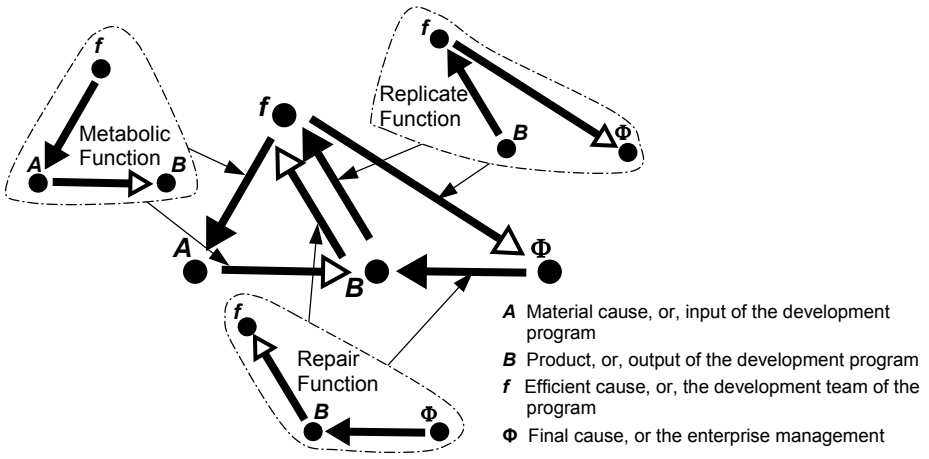


Figure 1. The M-R model and three types of morphisms

The term "function" in this article will be mainly associated either with capabilities of certain biological activities performed by organisms, or with capabilities of business or technical activities performed by enterprises. Where a mathematical function needs to be discussed, the context of the discussion will make it explicit.

2. Mathematical Discussions of Organic vs. Inorganic Enterprise Development

The previous discussions demonstrated that a PERA enterprise development program can be represented by Rosen's relational model shown in Figure 1. Following his mathematical definition in biology, the metabolic function of the enterprise program can be expressed as a mathematical function, or morphism in categorical language [Louie, 2004b][2],

$$f : A \to B \qquad (1)$$

where

A – Domain that represents the input of the development program. For each $a \in A$, a "specifies an environment of the system." [Rosen. 1971, p. 244]

B – Codomain that represents the output of the development program

f – The metabolic map that transforms A to B

Diagram (1) can also be equally presented as

[1] Rosen first published his M-R (Metabolism-Repair [Rosen, 1958a, p. 252]) model in a series of three articles [Rosen, 1958a, 1958b, and 1959]. [Louie, 2004b] and [Rosen, 1966, 1967, 1971, 1972, and 1973] are recommended for interested readers who would like to know how Rosen summarized his M-R model, and applied his mathematical tools.

[2] Readers who would like to learn more about category theory are referred to [Arbib, 1975] and [Pierce, 1991], which are self-contained introductory readings. [Arbib, 1975] may still be the only introduction to date available for non-mathematical majors.

$$f \in H(A,B) \tag{2}$$

where

$H(X,Y)$ – A Hom set, which represents a collection of all morphisms between Domain X and Codomain Y.

As shown in the previous discussions, Diagrams (1) and (2) represent the execution and implementation of an enterprise development program. Driven by the development team f that follows the development plan[3], input A is converted into B, the subject enterprise in development in this case. During the transformation process, manpower, brainpower, or machines including those for the purpose of management and control, can be involved as needed. Therefore, the metabolic function may be considered as common operations function in enterprise development.

Please note that since all environmental considerations are included into A, which represents Aristotelian material cause, the concept of input in Rosen's model is more than the demand of the enterprise development processes. All environmental impacts to enterprise development, say market, economical, political, etc. in the business environment, should be considered if the model is applied in the field of enterprise development.

Please also note that (1) and (2) and other diagrams later in this article should not be understood as descriptions only for machines or machine executables. As presented on Table 1 of the previous article, f stands for Aristotelian efficient cause that may represent people, and machine equipment as needed. That is to say, f is the active agent that carries out the needed actions in this metabolic function of the enterprise in order to obtain the result B. Any non-computability involved, such as innovative activities performed by human actors, should be included in f.

The relational considerations of the reasons why the final product B is created, and by what, are the focus of the mathematical exploration so that everything relevant will be included in the discussions. In other words, diagrams such as (1) and (2) in this article should be read as what *entails B* and why. Even time plays no immediate role at this level of relational thinking [Rosen, 1972, p. 227]. In order to better understand the roles of machines as well as time as a procedural parameter, a holistic approach should develop a strategy to think outside the box of machines and time. A choice for an exclusive approach to nothing but computability that is closely associated with machines will effectively prevent studies of enterprise development from discovering more effective solutions of utilizing machines if these solutions do not reside only within machines.

Therefore, it is important to understand that (1) and (2), and all other similar mathematical discussions in this study, are not confined within the boundary of studies for automatable procedures, even though procedural considerations will be included as a result. Otherwise, for example, the purpose, or Mission, Vision, and Values in terms of PERA [Williams, 1992 and 1996], of the enterprise development will have to be considered as a given from outside of the subject enterprise. Readers will find out in this article why this holistic framework of entailment relations is the very key to many important issues in enterprise development, including business alignment of enterprise information systems, which will differentiate organic enterprises from machines.

Even though the author has started to compare the concept of bio-functions with the common terms used in enterprise development, metabolism and operations for example, the readers have to be cautioned now that in the context of organic development, common concepts such as enterprise operations and strategies will become contextual and relative, which is quite different from the clear-cut machine world. Everything in the relational world that Rosen has revealed is *relationally interdependent* including operations and strategies. The biological backdrop throughout the discussions of this series is deliberately reserved to illustrate the rich perspectives illustrated by Rosennean model in order to help the readers appreciate the transitions back and forth between the machine model and the organic model.

The repair function in Figure 1 represents the activities of creating and maintaining the development team and the development plan for the enterprise program. To be consistent with Diagrams (1), (2) and Figure 1, let B represent either the specifications of the subject enterprise to be developed, or the enterprise in development. Let $f \in H(A,B)$ represent the development team and the development plan, including

[3] Note that same as in Rosen's abstract block diagram presented in the previous article, the formal cause that includes the development plan is implicit with the mathematical expressions. For the convenience of the discussions, therefore, f is considered a graphical representative of the formal cause as well.

other necessary facilities. And let Φ represent the enterprise management that formulates the plan and organizes the team. Then in order to develop and maintain the metabolic map in (1) and (2), the repair function in Figure 1 can be written as

$$\Phi : B \to H(A, B) \tag{3}$$

where

Φ – The repair map that converts B into the metabolic map $f \in H(A, B)$.

Similarly, Diagram (3) can also be equally presented as

$$\Phi \in H(B, H(A, B)) \tag{4}$$

Diagrams (3) and (4) demonstrate that the enterprise management should utilize available enterprise information and other resources under its discretion to prepare, develop, and maintain its development team and the plan, $f \in H(A, B)$. The repair function therefore may be considered as an enterprise strategy function in enterprise development. An immediate conclusion is therefore that the output of the metabolic function can be a constraint of the repair function since the former is the input of the latter.

Please note that in the study of enterprise development, PERA is still the only enterprise reference architecture that makes the definition of (3) and (4) possible. As presented in the previous article, among current reference architectures, only the enterprise life cycle of PERA starts with the concept identification of business initiatives about the subject enterprise. Therefore, at the beginning of PERA life cycle, management envisions and contemplates the conceptual model of the enterprise *B*, which is typically represented by the Mission, Vision, and Values of the enterprise to guide the strategic formulation of the development team, and the development plan, etc. Once the team starts implementing the development plan, more information about the subject enterprise will be available. Then the contents of *B*, the input to the repair function in (3) and (4), will become richer and richer through the life cycle of the development program.

When studies of PERA followed the industrial issues instead of particular technical solutions in enterprise development, it was inevitable to reach a firm conclusion: a complete definition of full life cycle of enterprise development that includes both strategies and implementation is so vital. In other words, the inclusion of the enterprise strategy function within the PERA life cycle is by no means a pure academic exercise, merely for the sake of the completeness of this definition.

When the strategy function is considered a foreign entity outside enterprise development programs, business requirements will become a given, or *a priori* [Uppington, 1998]. And then the main tasks of enterprise development so defined will become implementation oriented only. Since modern technologies and engineering can build, or at least simulate almost everything based on any idea that a human may generate, many industrial development projects and programs, which are guided by this siloed paradigm of strategy-implementation separation, may constantly face two potential risks: either leaving the whole development program at the mercy of some wild business dreams, or betting good business ideas on possibly ill-implemented development programs.

When [Wortmann, 1997] questioned the value of the claimed full descriptiveness of CIMOSA, he actually addressed the similar issues of ineffectiveness inherent within siloed management-engineering practice. However, neither an implementation-indifferent strategy nor a strategy-indifferent implementation will ever solve the problem.

The recognition of the full life cycle as defined by PERA is the very first step to find an effective solution. This holistic approach has to answer consequent challenges. Particularly, it seems that problems of the organized complexity [Klir, 2001; Weaver, 1948; and Weinberg, 1975] or non-computability [Rosen, 1991 and 2000] could become even worse in the field of enterprise development so defined, once the business side represented by strategic considerations are introduced into the field. But it could be true only if the scope of the study were confined within traditional industry automation with machine-based computability.

It is quite common to study separately the metabolic or operations function, (1) and (2), and the repair or strategy function, (3) and (4) and then single out the perspectives that can be computerized. However, the purpose of this study is to find out what could have been missed by these separated studies where the life cycles of enterprise development are artificially kept in silos, operations vs. strategies. The metabolic function and the repair function will be assembled together first to form "the simplest M-R system" in Rosen's words [Rosen, 1972, p. 234]. Then the replicate function will be introduced into the combination. No conditions of machine-based computability will be imposed during the discussion.

2.1 The Simplest M-R System As an Enhanced Machine Model Without Replicate Function

This simplest M-R system as illustrated in Diagram (5) and Figure 2 is an entailment combination between the repair function and the metabolic function. The repair function prepares the metabolic map $f \in H(A,B)$ for the metabolic function. The metabolic function in return provides reference materials B for the preparation of the metabolic map. For the simplest M-R system in Figure 2, if we consider B is the product in terms of Aristotelian causality, A will be the material cause of B, f the efficient cause of B, and Φ the final cause of B. In other words, each of them entails B in a specific way.

$$A \xrightarrow{f} B \xrightarrow{\Phi} H(A,B) \qquad (5)$$

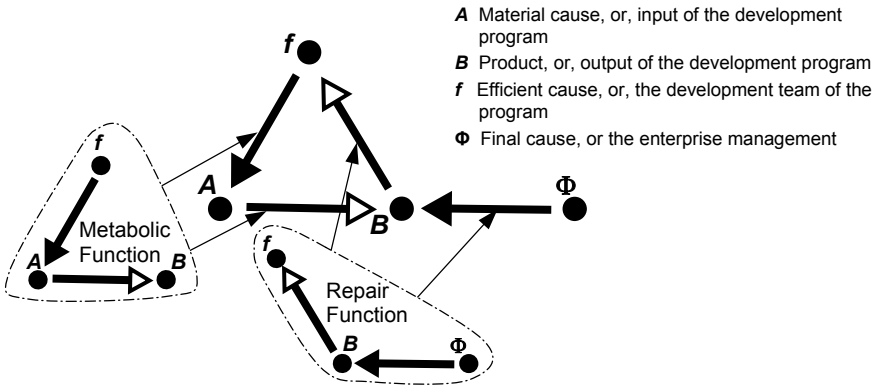


Figure 2. The simplest M-R system without replicate function

Note again that the concept of A-R entailment is relative and context-dependent. The causal terms listed in Figures 1 and 2, for example, are related with the product B. Similar discussions can be applied to the repair function in (3) and (4) as well, if f is considered the product of this repair function. In that case, B is the material cause of f, and Φ is the efficient cause of f. In other words, B and Φ each entail f in its own way. However, this type of entailment discussions shows that every object except Φ in Figure 2 is entailed. The readers will soon find out that the missing entailment for Φ represents the very reason why this simplest M-R system does not have fully organic potentials yet, even though it may partially represent them.

Under the A-R modeling framework, the efficient cause plays a special role in changing management. As stated above, it is always an action initiator or change agent that enforces the immediate actions to convert the material cause into the product in question. In order to initiate a change in this action initiator itself, however, another efficient cause will be needed in the context of the causal chain to produce the change in the change agent. Otherwise, the corresponding bio-map will stay as a fixed morphism. Then the efficient cause in question will only repeat the current actions.

Without the conditions defined in (3) and (4), for example, the metabolic map f defined by (1) and (2) would be a given or fixed morphism. Similarly, without the replicate function in Figure 1, the repair map Φ in (3) and (4) can be considered as given or fixed as well. Once (5) is formulated, it immediately makes it explicit that the repair function will mathematically restore or even alter the metabolic map f. The metabolic map f in (5) is then not fixed any more. And therefore, Diagram 5 and Figure 2 represent an improved machine model because of the additional flexibility gained from the repair function. However, the repair map Φ is still not entailed yet in (5). There is no internal drive or cause within the improved machine model for Φ to change.

In enterprise development, (5) represents a typical case where the enterprise development team f receives a program plan and associated instructions from a management entity Φ that is in charge of forming the development team and the program plan. The operations of the development, which are the implementation of the plan by the team, are now sustainable and even changeable under the enterprise maintenance and change management preplanned by the management Φ. However, this metabolic sustainability itself may only be kept under one condition: the decision made by the management Φ in this simplest M-R system can never be wrong. Otherwise, because nothing within the system of (5), as mentioned above, will correct the management, the enterprise strategy function will keep making the same

mistakes until some outside force replaces the erroneous management, or until the enterprise operations collapse, and so does the whole system.

Within the boundary of manageable changes, the cause of changes to the system in (5) may only present themselves through environmental input A. Without these outside changes, the enterprise management will simply maintain the existing metabolic function and keep the system stable, and so will the development team. The following discussions based on Rosen's mathematical approaches[4] will further demonstrate why this simplest M-R system above may still represent a reactive machine model. Although it has been improved much by the existence of the repair function, it may only offer limited flexibility in a changing environment. Please note that during the discussions below, the enterprise management Φ will remain unchanged all the way through as if it is a detached and indifferent commander of this enterprise who only acts based on his predetermined mind. As a matter of fact, the following relational discussion does not require that this indifferent management Φ physically stay in the same enterprise as the development team, as long as it maintains its authority in the command-and-control structure in question.

Given Diagram (5), the system then can be described as $\{f, \Phi_f\}$, where $f \in H(A,B)$, and $\Phi_f \in H(B, H(A,B))$. The subscript f in Φ_f indicates the initial association between f and Φ_f. Direct impact of environment can be represented by input $a \in A$, and consequently, the metabolic map f presents the result b as follows:

$$b = f(a) \quad a \in A, b \in B \tag{6}$$

From Diagrams (2), (3), (5) and Equation (6), when the system maintains its stability in (5) with the two bio-functions, the following equation represents the stability of the system at the level of the metabolic map:

$$f = \Phi_f(b) = \Phi_f(f(a)) \tag{7}$$

The importance of the stable condition in Equation (7) is not limited for the repair function. A stable metabolic function also demands a stable metabolic map for the metabolism in (6) as well. In a changing environment, however, the change impact may well make it necessary for Φ to repair and alter the metabolic map so that the stability can be restored or maintained.

Assume that environmental changes have led to new input $a' \neq a \in A$. Then, in order to maintain the stability of the enterprise development, i.e., in order to mathematically maintain Equation (7), ideally without any need for a structural change in f, at least one of the following two conditions will be achieved, for example, under feed-back or feed-forward control with the metabolic function f:

$$f(a) = f(a') \tag{8}$$

Or

$$f = \Phi_f(f(a')) \tag{9}$$

If, however, the condition specified in Equations (8) or (9) is not manageable to continue with the original development team or plan, i.e.,

$$f' = \Phi_f(f(a')) \neq f \tag{10}$$

That is, the changes in environment have caused structural changes in the metabolic map in order to maintain its stability. The originally stable operations, f, have to be replaced now by a different one such as $F = \{f' \mid f' \in H(A, B)\}$. Given the options available to restore the needed program stability, each of the following outcomes is then possible:

1) The new program operations under the new environment will offer the same output, which is
$$f(a) = f'(a') \tag{11}$$
2) The new metabolic function under the new environment restores the original development operations, possibly with adjusted or altered output, $b' = f(a'), a' \neq a \in A, b' \neq b \in B$:
$$f = \Phi_f(f'(a')) \tag{12}$$
Usually, changes in environment are inevitable. Therefore, Equations (11) and (12) represent consequent changes in operational structure in development.

[4] Please see [Rosen, 1972, pp. 244 – 246] for his discussions on considerations for biological systems.

3) The new metabolic function under the new environment finally leads to a permanent change represented by a newly stabilized development program, possibly with permanent changes to the output as well.

$$f' = \Phi_f\left(f'\left(a'\right)\right) \tag{13}$$

4) The reactive adjustment during the enterprise development is not able to catch up the changes in environment:

$$f'' = \Phi_f\left(f'\left(a'\right)\right) \neq f, f' \tag{14}$$

In Rosen's word [Rosen, 1972, p. 244], this simplest M-R system in (14) has to "hunt" throughout possible relational combinations available in $H\left(A,B\right)$ for the stability of its program development through a sequence of different operational arrangements, which are represented by

$$F = \left\{f, f', f'', \ldots, f^{(k)}, \ldots \middle| f^{(k)} \in H\left(A, B\right)\right\} \tag{15}$$

If an n_0 does exist so that it satisfies

$$f^{(n_0-k)} = \Phi_f\left(f^{n_0}\left(a'\right)\right), \quad k = 1, 2, \ldots, n_0 - 1 \tag{16}$$

i.e., even if the condition in Equation (16) can be found among available operational options built into $H\left(A,B\right)$, the system will most probably still have to go through a series of periodic changes. Otherwise this M-R system will be forever "unstable and aperiodic" [Rosen, 1972, p. 245] in an infinitive search as shown in (15), which can be now defined as $\left\{f, f', f'', \ldots, f^{(k)}, \ldots, \Phi_f\right\}$, where each element $f^{(k)}$ represents a candidate operation plan, probably with the needed operation team as well.

Please note that the above discussions are lenient because it not only embraces changes in input *A* but also permits changes in output *B*. That is, the search space, $H\left(A,B\right)$, for a stable metabolic map through enlarged *A* and *B* may also become infinitive. It is possible to discuss any of these infinities in theory, but it is impossible for any sustainable enterprise program in the real world to go through even one of them.

The above discussions are lenient also because the causal formalism of the discussions above does not necessarily require each candidate metabolic map $f^{(k)}$ as shown in (15) is computable, as stated previously. Since Φ_f represents the final cause or the purpose of the simplest M-R system, the computability of Φ_f is also not required. The recognition of the purpose Φ_f indicates that this simplest M-R model, although it still represents machines, explicitly embraces the purpose of humans.

Discussions from Equations (6) to (16) illustrate that even for an enterprise that follows this enhanced machine model, equipped with multiple operational options as shown in Equation (16), its performance can at best be reactive and periodic by trailing the changes in environment. Optimistically, it seems that an outside help, which is able to keep adding more operational options $f^{(k)}$ into the system, may work. But technically and economically, since it is impossible and cost-prohibitive for enterprises to have unlimited available options for their operations pre-built so that they could handle every unforeseen change, this argument only presents an approach of infinitive reactions, which is impossible in business or engineering practice. The outside party that would be presumably capable of finding the additional options under this argument presents another issue of infinity because this outside party would face the exactly same issue: it is impossible to develop unlimited options either.

Therefore, when the changes fall outside of available operational options embedded in the existing development program that follows machine models, it is very common for enterprises to be trapped infinitely in reactive mode in their operations. Or even worse, they would diminish sooner than planned when their systems failed to adapt with limited resources available. Please note that the discussions in this session have not resorted to time, but the conclusions may have everything to do with time, i.e., the life or life cycles of enterprises.

When the simplest M-R system switches from one operations package $f^{(k)}$ to another $f^{(k+1)}$, the system will demonstrate a pattern of development life cycles that represent the end of the last operational

package and the beginning of the next. Particularly, when the difference between the packages are small enough, the changes of the system between the life cycles will appear to be iterative and incremental. However, these epistemological patterns do not necessarily mean that the system has already retained the fully organic potentials, according to Rosen's M-R model.

2.2 Inclusion of Replicate Function to Be Fully Organic

The solution to the adequate internal change management, which even the improved machine model shown in (5) is not able to offer, has everything to do with the missing entailment for the enterprise management, i.e. the absent efficient cause of Φ in the machine model as shown in Diagram (5) and Figure 2. If found, this efficient cause of management Φ will be the needed active internal drive and change agent for the management to proactively create new strategies in preparation for a changing environment. Since no organism has ever possessed unlimited resources or lived forever, they must internally have something as such that makes them more self-sustainable than any machines facing changing environment.

Rosen demonstrated that his model of organisms, M-R model in Figure 1, must include the replicate function that internally repairs or regenerates the repair map to make the M-R model truly organic. Although Diagram (5) only includes two out of the three bio-functions, Rosen pointed out that since organisms have developed all three bio-functions, the simplest M-R system shown in (5) should organizationally have the potential to develop the third one, the needed replicate function [Rosen, 1972 and 1991], *if and only if* it has correctly presented the other two, metabolic and repair.

As shown in Figure 3, the structure of Diagram (5) has provided clues to the needed solution. Diagram (4) indicates that should the repair map $\Phi \in H(B, H(A,B))$ be as "reparable" as the metabolic map $f \in H(A,B)$ in Diagram (5), $H(B, H(A,B))$ would be the output of the desired replicate function. The composite form of $H(B, H(A,B))$ indicates that the repair map $\Phi \in H(B, H(A,B))$ becomes more relational than the metabolic map $f \in H(A,B)$ in terms of their output. Therefore, in order to be even more relational, the replicate map, which is needed to form the replicate relations, would most probably have a relational input. This observation then makes the codomain of the repair function, $H(A,B)$, an ideal candidate for the domain of the replicate map, as shown in Figure 3. Then the next step is to find out if one more map, mappings from *f* to Φ, represented by the question mark in Figure 3, can be constructed, probably with additional conditions based on the available relations within Diagram (5).

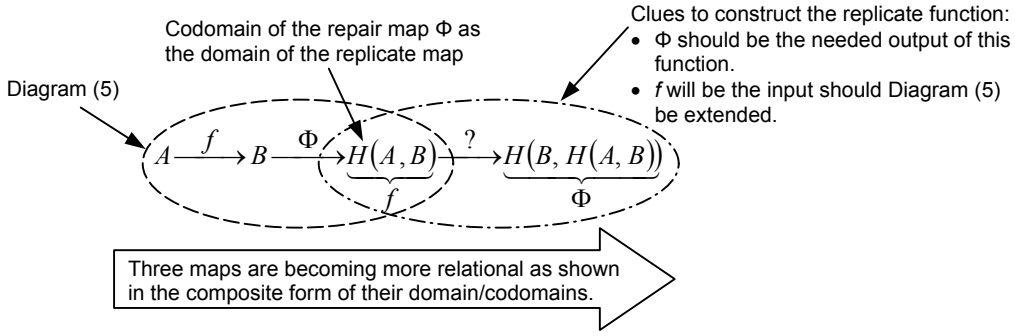


Figure 3. Clues to formulate the replicate function based on the simplest M-R system in (5)

The repair function in Diagrams (3) and (4) with the simplest M-R system already contains a subsystem of mappings from Φ to *f*, which can be considered as an enterprise performance measurement system. Since (3) and (4) can be also expressed as $\Phi(b) = f$, this subsystem of performance measurement can be shown below[5], for each $b \in B$,

$$\hat{b}(\Phi) = \Phi(b) = f \qquad (17)$$

where, $\hat{b} : \Phi \to f$

[5] For this generic mathematical manipulation with (17), interested readers are referred to [Casti, 1989a, p. 21; Kato, 1980, pp. 15 – 16; and Rosen, 1972, p. 245].

In the context of enterprise development, $\hat{b}$ can be considered as an institutionalized performance evaluation of the enterprise development team, based on the performance standards generated from the requirements of the management. For each $b \in B$, from Diagram (3) or (4), the comparative map $\hat{b}$ imbedded within output B, which connects the management and the development team, can also be expressed as

$$\hat{b} : H(B, H(A, B)) \to H(A, B) \tag{18}$$

Or

$$\hat{b} \in H(H(B, H(A, B)), H(A, B)) \tag{19}$$

Therefore, the inverse of $\hat{b}$, if exists, will form the needed mapping "?" in Figure 3 from the metabolic map to the repair map. Rosen has defined $\hat{b}$ as an injection, which is a one-to-one map or a left inverse, in order to construct the needed replicate map. By left-multiplying both sides of Equation (17) with $\hat{b}^{-1}$, for a given f, the following equations are then established:

$$\hat{b}^{-1}\,\hat{b}(\Phi_f) = \Phi_f = \hat{b}^{-1}\,\Phi_f(b), \text{ or, } \hat{b}^{-1}\,\Phi_f(b) = \Phi_f \tag{20}$$

At the same time, following Rosen's symbol, define the replicate map as $\beta = \hat{b}^{-1}$, and then after taking (17) into (20), i.e.

$$\underbrace{\hat{b}^{-1}}_{\beta}\,\underbrace{\Phi_f(b)}_{f} = \beta(f) = \Phi_f,\ f \in H(A,B),\ \Phi_f \in H(B, H(A,B)),$$

the following replicate map β can be defined as the left-inverse of Diagrams (18) and (19):

$$\beta : H(A, B) \to H(B, H(A, B)) \tag{21}$$

where, β – The replicate map that transforms the metabolic map into repair map.

Or

$$\beta \in H(H(A, B), H(B, H(A, B))) \tag{22}$$

Please note that the domain and codomain in (21) and (22) themselves represent relational maps. That is to say, the replicate map represents relations about relations. This relational role played by β in the context of enterprise development can be considered as a change agent for the strategic growth of the enterprise management, which is the output of this morphism. This efficient cause, the change agent, of management is however relational itself: it is not management or development team per se, but their relations in between, which do not generally exist in machine models such as Diagram (5). It also indicates that the development team and the associated development plan, etc. as the resource of the relational transformation, may become a constraint of this strategic growth.

As indicated by Diagrams (21) and (22), the replicate map β represents relationships between the other two maps, metabolic and repair maps. At the same time, Equation (17) indicates that such relationships must be formed while the repair map develops, replenishes, or repairs the metabolic map as shown in Equation (23) below:

$$\hat{b}(\Phi) = \underbrace{\Phi(b) = f}_{\substack{f \text{ is being} \\ \text{repaired}}} \tag{23}$$

Therefore, the change agent β in the replicate function, together with $\hat{b}$ as performance evaluation, represents an organic organizational capacity that is developed in the interactions reciprocally between the enterprise management and the development team while they each fulfill their own causal roles as different change agents. Therefore, although it is possible to import a development team, or even enterprise management, into an enterprise development program, the organizational capacity represented by β can never be imported or bought from outside. It must be developed through the interactions from within between the team and the management.

In terms of enterprise performance management, if $\hat{b}:\Phi \to f$ is compared with $\beta : f \to \Phi$, $\beta = \hat{b}^{-1}$, the requirement for the one to one map β indicates how an organic enterprise performance management should be conducted reciprocally and complementarily through official organizational hierarchy: all levels of the enterprise development will systematically manage up where the enterprise management manages down in a manner of one-to-one through functional relationships[6]. Although more studies are needed on this subject, performance management driven by the end results, as illustrated by $\beta : f \to \Phi$, does represent a corporate cultural environment that values the contributions from bottom up, and encourages the manage-up practice [Gabarro, 2005]. It will be impossible for the Rosennean replicate function to exist in an organizational environment where the performance measurement is conducted in a strictly hierarchical and unilateral manner from top down as shown in Equation (17), $\hat{b}:\Phi \to f$.

Since the enterprise management $\Phi \in H(B, H(A,B))$ becomes the codomain of the replicate function, Diagrams (21) and (22) indicate that the enterprise management under the given condition has found its own efficient cause β within the M-R model, and then, and *only by then*, it has become an internal part of the enterprise development. Once Diagrams (5) and (22) are combined, the complete mathematical expression of the M-R model with all three bio-functions can therefore be expressed as

$$A \xrightarrow{f} B \xrightarrow{\Phi} H(A,B) \xrightarrow{\beta} H(B, H(A,B)) \qquad (24)$$

where,

$f \in H(A,B)$, i.e. the metabolic function;

$\Phi \in H(B, H(A,B))$, i.e. the repair function;

$\beta \in H(H(A,B), H(B, H(A,B)))$, i.e. the replicate function.

(24) indicates that every object in Figure 1 including Φ is now entailed. Rosen pointed out that Equation (20) demonstrates that the repair map Φ is relationally different from the metabolic map *f*. The metabolic map under the M-R model in (24) may be changed as the environment changes, similar with its counterpart under the simplest M-R system as shown by Equations (10) to (16). The repair map Φ will however conserve itself through all possible environmental changes. The only way to modify the repair map is "to operate on the 'genetic' maps directly" [Rosen, 1967, p. 93] through the replicate map β. In other words, β represents an organic potential to allow organic systems to proactively adjust the repair function from within.

An immediate conclusion is that since it is impossible for organisms to possess with their birth unlimited metabolic maps, as indicated in Equation (15), to prepare for their lives in a harsh natural environment, their stable growth must be supported by internal revisable repair functions that are capable of maintaining their organic identities on the one hand, and proactively regenerating the needed replicate map to adapt them to a changing environment on the other hand.

Before the replicate function joins the M-R model as such, discussions of Equations (6) to (16) under the simplest M-R system have demonstrated that the mathematical one-to-many relations between Φ and *f*, which represent a rigid strategic management with a few operational options, may offer at best preplanned adaptation. There the major entailment relations between management and operations team are nothing but command-and-control of management to search for pre-designed solutions, if they exist, forced by environmental changes. Please note that in enterprise development that follows the machine model, since the management is not able to consider any new environmental influence outside predefined strategies, it operates actually in a different organizational silo from the reality of operations, even if the management is physically in the same location, say in the same building where the operations team is located.

Once the replicate function joins the M-R model as shown in Diagram (24), the strategy of change management is changed from being external oriented and therefore reactive under the machine model, to being internal oriented and therefore proactive. The mathematical one-to-one relations between Φ and *f* in Equation (24) indicates a close causal association between the management and the operations team. Any

[6] $\hat{b}$ as an invertible map may not be full while it is one to one. Otherwise a bijective replicate map as such would imply that the organic development was deterministic. If the metabolic map were fully pre-determined, it would leave no room for an organic system to evolve. This organic property is however outside the scope of this article.

change initiatives, no matter whether it is generated by the management or the operations team, will most probably receive immediate response from the other party. The active and reciprocal interactions represented by β between the management and the operations team will drive from within strategic changes, which do not have to wait for outside intervention. Once this relational driver β is formed internally under the organic model, the association between operations and management will replace the isolation between the two under the machine model. Please note that such result-oriented A-R causal relations do not necessarily demand that both the management and the operations team be in the same physical location, though the same location may help.

An active replicate function is vital for enterprise strategic vigor in a changing environment. The same entailment rule is applicable through all levels of the enterprise development including the senior ranks. Kevin Sharer, the CEO of Amgen, once compared his previous experience with the management teams at GE and MCI [Hemp, 2004]. He was used to expectations at GE where new managers should initiate change in strategy to strengthen business. However, after he joined MCI, the same approach made him soon isolated within the management team, and eventually he was advised by the CEO to leave.

Kevin recounted his MCI experience as a personal flip: he had not realize soon enough that his change proposal could become a political dissident under then single overwhelming strategy at the pre-WorldCom MCI to "get AT&T" [Hemp, 2004]. However, the sharp contrast between two different cultures, GE vs. MCI, of strategy management illustrates that GE has developed and maintained an organic replicate function at least among the managerial ranks to ensure adequate change management of strategy growth.

The relational replicate function may come with many forms and shapes in enterprises with different background. Tadashi Kume, then a chief engineer of Honda R&D, resigned when he failed to present his case of water-cooling to the founder of Honda, Soichiro Honda, who was then a "bullheaded" [Shook, 1988, p. 23] believer of air-cooling. After Kume was lured back, he and his "all-or-nothing" team built a revolutionary water-cooled engine in a year. Honda took this lesson so seriously that it thereafter developed and institutionalized an all-involvement decision culture.

When Honda came to US, it was the first Japanese automaker entering into this market, and not many outside people believed that this "maverick company" in Japan [Shook, 1988, pp. 11 – 14] would achieve the same quality and productivity in US. Once Honda set up a manufacturing base at Marysville, Ohio in 1978, it brought the same strategy management system to its US managers and employees who had a strong farming background[7]. A title, Honda Associate, has been applied to all managers, employees, and even preferred suppliers ever since. Starting from the early days of HAM (Honda of America Manufacturing, Inc.) an approach of group discussions on all subjects has been normalized through all levels of the company. Until today, HAM still has a well-known reputation of decision making by consensus: a consensus has to be reached among all people involved, managers or common employees alike, no matter where this decision is made. Today, not many people will refute the fact of the steady and organic growth of Honda in US. But probably only a few will acknowledge, "it was Honda's *managerial* innovations that transformed a group of central Ohio people into a highly motivated and inspired work force." [Shook, 1988, p. xvi, italics in the quote is original][8] The innovation in business strategy may well be the desired results in general, but without the institutionalized replicate function, strategic innovation can only be exceptional in an enterprise that follows the machine model.

The replicate function of the M-R model represents one of the most important conclusions of Robert Rosen. Natural selection should not be considered as the sole driving force behind the evolution of organisms [Rosen, 1991, 2000]. Life itself represents more than passive beings that may only follow the rule of "survival of the fittest." Instead, supported by the inherent replicate function, organisms are full of the internal potentials to self-sustain and evolve proactively. For applications in enterprise development, the passive Darwinian views advocated in some organizational studies may support researches for

[7] In 1978, "HAM officials decided to hire people who lived within a thirty radius of the plant. All of these men and women would be gleaned from the small towns and farming areas in rural central Ohio" [Shook, 1988, p. 45]

[8] In addition to [Shook, 1988], interested readers may be referred to [Nelson, 1998] where the authors presented their personal stories with HAM and its suppliers. In 2001, this author led an IT consulting team working on a project of Honda Value Chain for both HAM and its IT capacities, and gained the first hand knowledge and experience from committed and strategically-conscious Honda associates at Marysville, Ohio.

identification of macro-patterns in enterprise development by deliberately overlooking the internal driving forces. However, approaches as such cannot explain well the effort and choice made by active human agents within enterprises [Morgan, 1997, pp. 68 – 71], needless to say that not every enterprise is qualified to be organic according to Rosen's model, once it is introduced into the field.

In the context of enterprise development, in order to be Rosennean organic, the life cycles of the enterprise program must contain the necessary entailment relations described by all three bio-functions in the M-R model. These organizational relations will enable the enterprise management to make active and appropriate strategic adjustment to their business models, including their business plans and strategies, so that the enterprise development does not have to be trapped in an infinitive chase after unattainable business sustainability as illustrated in Equations (15) and (16).

Compared with machine models, including the enhanced one shown in (5), the M-R model represented by Figure 1 and Diagram (24) demonstrates well-knitted internal relationships between the three bio-functions. Although the above discussions are developed one by one through the three functions, once the replicate function joins the M-R model, all three of them must collaborate closely as an inseparable whole to produce and sustain an organic organization as shown in Table 1. Some criticisms [Goertzel, 2002; and Landauer, 2002] have suggested replacements for Rosen's replicate function. They however have not been able to offer anything to reconnect the then missing internal links, as shown within the double-lined boundary in Table 1, between the bio-functions. Without the replicate function as defined by Rosen, the M-R model will be reduced into a machine model, even though it may be improved as shown in Diagram (5).

Table 1. Holistic inter-relationships between the three bio-functions as defined in the M-R model

	Metabolic Function	**Repair Function**	**Replicate Function**
Metabolic Map *f*	*Map: $\boldsymbol{f} : A \to B$	Output: $\boldsymbol{f} \in \boldsymbol{H}(\boldsymbol{A}, \boldsymbol{B})$	Input: $\boldsymbol{f} \in \boldsymbol{H}(\boldsymbol{A}, \boldsymbol{B})$
Repair Map Φ	*Receiver of the Output: $\boldsymbol{\Phi} : \boldsymbol{B} \to H(A, B)$	Map: $\boldsymbol{\Phi} : B \to H(A, B)$	Output: $\boldsymbol{\Phi} \in \boldsymbol{H}(\boldsymbol{B}, \boldsymbol{H}(\boldsymbol{A}, \boldsymbol{B}))$
Replicate Map β	Relational Entity Embedded in the Output: $\boldsymbol{\beta} = \hat{b}^{-1}$ where, $\hat{b}(\Phi) = \Phi(b),\ b \in \boldsymbol{B}$	Receiver of the Output: $\boldsymbol{\beta} : \boldsymbol{H}(\boldsymbol{A}, \boldsymbol{B}) \to H(B, H(A, B))$	Map: $\boldsymbol{\beta} : H(A, B) \to H(B, H(A, B))$

*Note that the descriptive items in the cells of the table should be read as "*the* <Row Head> *is the* <Descriptive Item in the cell> *of the* <Column Head>." For example, *the* Metabolic Map *f is the* Map *of the* Metabolic Function. *The* Repair Map Φ *is the* Receiver of the Output *of the* Metabolic Function.

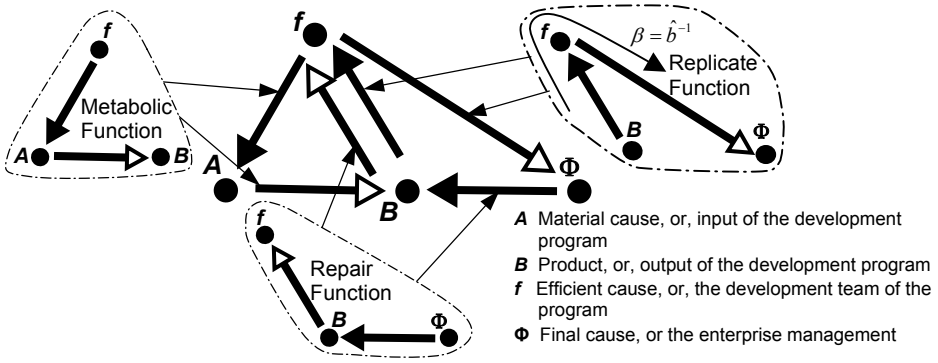


Figure 4. The M-R model with explicitly illustrated replicate function β

Graphically in an ABD diagram, it is convenient to explicitly demonstrate metabolic and repair functions, since *f* and Φ themselves are efficient causes for their relevant causal products as shown in Figures 1 and 2. It is not so convenient though for the replicate function β since it is an inverse of $\hat{b}$ mathematically,

which can only be explicitly and accurately shown in Diagram 24. In order to remind the readers of the relational existence of β, an explanatory arrow is added by the author from now on to the replicate function as shown in Figure 4, to emphasize the existence of this purely relational object β in the M-R model.

3. Holistic Nature of Being Rosennean Organic

The above discussions have shown that facing changing environments, enterprise development with limited physical and financial resources will be either at best reactive and periodic by following the machine model, or will be able to self-evolve with desired adaptivity by following the Rosennean organic model. Such organic enterprises will have to be anticipatory [Rosen, 1985b] at the strategic level. Through generations of their life cycles, the enterprise management and their organic enterprises will evolve progressively as needed, or bifurcately to fit into dramatic changes in environment.

Please note that the concept of anticipatory systems from Rosen includes but is far beyond the common concepts of feed-back or feed-forward control in engineering. The organic systems as identified by Rosen do not limit their "control actions" at the level of metabolism by manipulating the parameters associated with either input A or the metabolic map f in Diagrams (1) and (2). The Rosennean anticipatory systems will also organizationally and institutionally manipulate through all three bio-functions as shown in (24), not only within one life cycle, but through generations of life cycles as well. Otherwise, at least, the ability of organic bifurcation will be impossible without changes at the levels of repair function and replicate function. The holistic inter-relationships between the three bio-functions shown in Table 1 thus are not optional but necessary for organic development.

As discussed previously, the replicate function plays a vital role under the anticipatory system in enterprise development. In order to become anticipatory, instead of reactive, the organic organization prepares for possible changes starting from the strategic level, since the common feedback loop at the operational level with the metabolic function $f \in H(A,B)$ is not adequate any more. In addition to the performance management discussed previously, the replicate function $\beta \in H(H(A,B),H(B,H(A,B)))$ provides the necessary and active entailment links between operations team and enterprise management so that the anticipatory strategies can be efficiently experimented, monitored, and measured. In a sense, the replicate function represents the organic growth function of enterprise management. Please note that, because of the necessary and direct involvement of the operations team in this organic strategy development, enterprise operations function and strategy function are not as exclusive from each other as their counter parts under the machine model: the difference between them is not absolute but relative and contextual.

For similar reasons, in the context of organic development, iterative and incremental development throughout life cycles represents one of the natural results, instead of the reason, of being organic at both strategic and operational levels to explore the future opportunities. Although the purpose of the anticipatory actions is to explore new opportunities and directions, the internal changes initiated by the internal change agents must start with the relations and materials that are currently available. Although certain time lags within and between bio-functions are allowed, an organic life cycle must be able to reach and manage functional stability within limited lifetime [Rosen, 1972, pp. 227 – 229]. If possible, incremental improvements that will accumulate bigger changes should therefore be favorable under the concerns for stability.

In order to sustain such internal stability, as shown in Table 1 for example, the replicate function β cannot regenerate the repair map at a rate that exceeds the allowance of its input, the metabolic map f. The repair function Φ cannot repair the metabolic map at a rate that exceeds the allowance of its input, the product B. The metabolic function f cannot operate at a rate that exceeds the allowance of the environmental input A. After all, a healthy balance between the three bio-functions should be properly maintained. A holistic iterative and incremental approach will most probably impose minimum disturbance throughout the system. In an organic enterprise, management and operations team involved in the iterative and incremental development will also have opportunities to learn from each other over strategic issues, since operations and strategies are closely associated as discussed previously. Therefore both parties will be prepared for more aggressive change when it is necessary.

If an organic enterprise does not support iterative and incremental development, it must be either currently gong through strategic bifurcation, i.e. aggressive changes, or such an iterative and incremental

approach must be somehow physically and structurally infeasible given the nature of the enterprise operations, for example, building up a huge dam on a large river with a steep drop. Or otherwise, this enterprise may not be organic at all.

The relational integration of the three bio-functions in this holistic model represents the results of organizational entailment within organic organizations, which are rich in terms of multi-perspectives. A common misunderstanding is to reduce this organizational and relational entailment back into purely material concerns or else equivalent. There are profound reasons that this A-R entailment study should not be understood only as common metaphor, or analogy [von Bertalanffy, 1969, p. 84], at the level of physical, computational, or financial connections[9].

When Rosen started with the famous question, "What is Life?" he did not stop with the common epistemological studies of physical appearance of life or machine, but further ontologically explored the underlying reasons why an organism is alive in general, and what makes an organism different from a machine. Equipped with Aristotelian causal framework and his category theory, Rosen reconfirmed with his M-R model that only after all material concerns are removed, can the hidden relational entailment patterns underpinning the existence of the systems, machines or organisms, be revealed.

In enterprise development, for example, not all relations can be measured in material terms by immediate cash values. Particularly, only the entailment relations described in the machine model may be physically realized within machines, mechanical or digital. And the calculation of the cash values of the machines is therefore feasible. However, it will never be the case with organic enterprises as defined by the M-R model. The relational nature of the replicate function listed in Table 1 typically illustrates why the rich multi-perspectives that reside within organic systems should never be discounted.

In the context of replicate function, for example, although a first look may exhibit many ways to collect information from the development team and its members represented by f in Figure 1 to generate and regenerate a better enterprise management Φ, the quality of the information will ultimately depend on the personal and professional values that are held up by the members of the team because of their human natures. These values may well be different from the cash values created by the enterprise operations. If the interactions between the development team and the enterprise management prove that the enterprise management is indifferent in helping the members of the team to achieve their values, there will be no reason for the members to consider anything more than the enterprise operations under their direct responsibilities. Therefore, the necessary institutional driver β that is needed to activate the special organic resource f in $\beta : f \to \Phi$ will not be in place. That is to say, f, the relational "material cause" of Φ in replicate function as shown in (21) and (22), does not necessarily "compute" the same as A, the material cause of B in metabolic function in (1) and (2): the relational f is an active agent, not as passive as physical materials in A. Therefore, the replicate function will never exist under a corporate culture that undervalues human capitals.

In this case, when the enterprise management treats the team members in operations the same as physical machines that should only follow instructions and send back data through formal reports just like pre-installed "sensors", the management has actually detached themselves from operations of the enterprise development, and forgone the potential strategic values rooted in the operations. As a result, the enterprise development as a whole will behave exactly like a machine. The machine model in both Diagram (5) and Figure 2 illustrates the consequences once the replicate function is so removed: what goes around comes around.

When the Industry-Purdue Consortium developed the Purdue Methodology, the Consortium found that it was those who usually came forth first from the development team that identified most of innovative initiatives of enterprise development programs. These people were named as Program Champion under the Purdue Methodology [Williams, 1996]. While the Consortium spent time at length to develop the Human

[9] [Casti, 1986, 1988, 1989a, and 1989b] first attempted to apply Rosen's M-R model in his studies of manufacturing industry. He built his relational case mainly based on the concept of cash flow that establishes the financial connections between enterprise operations and maintenance. The rich perspectives of relations including the roles of human agents in enterprise development are therefore unfortunately missing from his study. If monetary concerns could fully represent the purpose of an M-R system, and if the entailment relations between the three bio-functions could be fully calculated based on economical and financial criteria, the non-computability, one of the core concepts of the M-R model, would have not been valid for manufacturing enterprises.

and Organizational Architecture as an irreplaceable part of the develop programs, the issues of corporate culture, including the fate of these Program Champions after the programs were finished, were recognized as part of organizational infrastructure. All these considerations would not be so necessary if the enterprise programs followed machine models, which always assume that the programs should be initiated from outside, or from top down.

Since it is the enterprise management that directly controls the financial resources of development programs, once the business needs for organic development are justified, the management in charge has to commit itself to the whole program, and nurture the needed interactions with the development team so that both the management and the team truly become an internal part of the development to gain the full benefits of the organic relations. In terms of PERA, they should grow together under the Human and Organizational Architecture of an organic enterprise. In other words, in its manifestation, β should be realized with the implementation of the Human and Organizational Architecture as well as technical facilities as needed.

The development of the organic Human and Organizational Architecture are beyond the single matter of business innovation, or productivity management. Any businesses may import innovative ideas, technologies, or even star employees and star executives from outside in various ways. However, the imports will not be able to change a machine enterprise into an organic one if they cannot develop the enterprise replicate function. That is to say, their achievement if any will not become the seeds for future growth in a machine organization: the initial results at best will not be sustainable once their powerful influences are over. Needless to say, a machine enterprise may maintain certain level of productivity under a hierarchically imposed command-and-control measurement system, but it will not be able to grow the flexibility needed in a changing environment.

What the organic replicate function has emphasized is the *relations* β between management Φ and operations f driven by business that is represented by A-R product B, where β is imbedded. What and how the *relations* are manifested and substantiated in the physical world will ultimately depend on the management, the operations, and the business needs involved. The PERA Program Champions who come forth from engineering rank with their innovative initiatives for new development programs represent one of the outcomes of an organic enterprise development. The GE managers who have change proposals based on newly gained insights through business operations represent another possible outcome. The Honda associates who are supported, and facilitated by management to keep refining their production policies and operational procedures also represent a possible outcome. They are all *strategic* representatives for the A-R relational function in the relational world.

Therefore, the enterprise replicate function and the organic Human and Organizational Architecture within an organic enterprise stand for an organizational infrastructure and institutionalized business practice to establish, between the management and the operations, intra-enterprise human relationships that promote and sustain improvement and innovation in business strategies.

Please note that for an organic enterprise, the replicate function does not represent a goal but on-going business practice just as what the metabolic and repair functions stand for. As a result, the enterprise management, the development team, and the development program will be able to grow, develop, and evolve together during the course of interactions with a changing environment. No matter how advanced it is, digital connectivity that facilitates the implementation of the Human and Organizational architecture may only assist, not replace, these interactions between the management and the team. The technical implementation architectures of the digital connectivity should therefore always be compatible with, and dependent upon the "people architecture," not the other way around[10].

For similar considerations, the authors introduced elsewhere [Li, 2004] a necessary condition of technical independence for holistic enterprise reference architectures that should address all important issues in the field of enterprise development. Computer-executable syntax should not become a constraint of the descriptiveness needed for the program specifications in enterprise development. Otherwise, approaches to enterprise development will be confined within computerized information systems without

[10] Even under the machine model, the PERA principle of "people first" in engineering is still necessary though it may be simpler. For example, designs and training programs that help human agents follow procedures of operations and make fewer mistakes are still important. However, these human agents will be ultimately treated the same as other components in enterprise operations that follow the machine model.

adequate entailment perspectives for effective business alignment, since business requirements have to be then filtered out as a foreign entity from an outside business system as discussed early in this article.

The holistic growth is however impossible for enterprise development that follows the machine model, where the development team is expected to be a passive follower of the management under the repair function. Under the machine model, the development team is only supposed to receive instructions from the management, while the enterprise management on the other hand only manages from top over the existing program plan with limited options. Particularly, the management will have no reason to push itself for any change and improvement until such a change is imposed from outside. In an ideally stable environment as discussed above, the subject enterprise then only represents the results of the original development plan. The enterprise management and the development team will therefore remain in different organizational silos with siloed responsibilities, as shown in (a) of Figure 5.

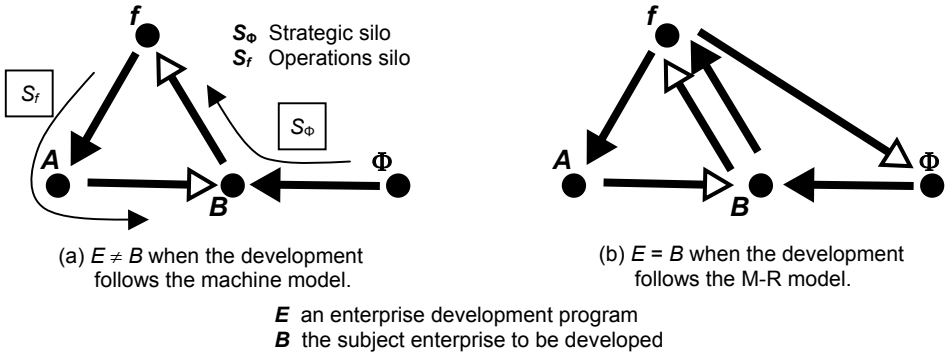


Figure 5. Holistic practice vs. siloed practice in enterprise development

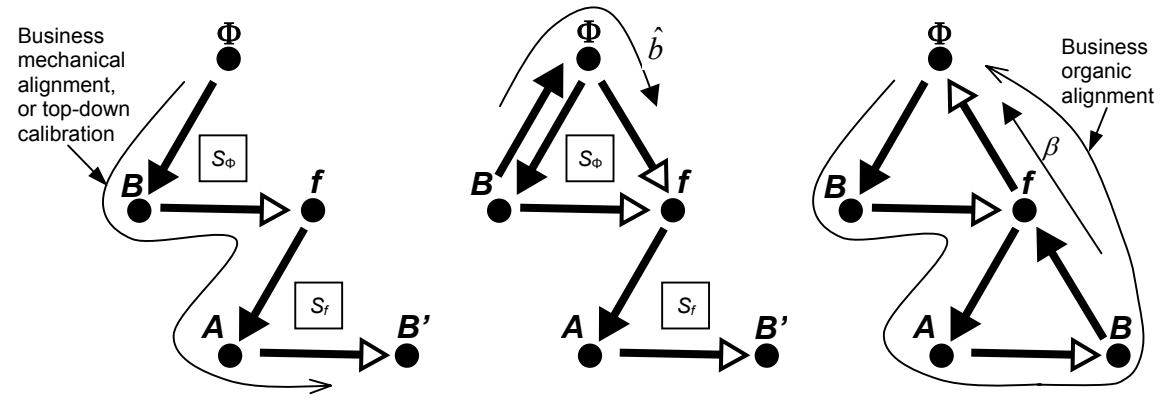
In (a) of Figure 5, strategic silo, S_Φ, is committed to the plan generation and the team formation, and operations silo S_f is committed to the plan execution by the team since the development team f is a passive receiver of the plan. Therefore, when development programs follow the machine model, one organization may well demonstrate two split "personalities": operations vs. strategies, due to the existing gap between the two silos[11]. Each of the two sides may only have half of the "picture" since they each are trapped in their own silos.

Since the team f in (a) of Figure 5 is considered a passive result of silo S_Φ, it is only supposed to follow the development plan and the specifications of the subject enterprise, which are prepared by the management, represented by B in (a). But how closely the implementation will operate according to the original specifications and plan can be a question under the siloed practice, especially when the environment changes.

(a) of Figure 6 may make the two organizational silos, S_Φ and S_f in (a) of Figure 5, more explicit in a hierarchical view. (a) and (b) of Figure 6 illustrate that the lack of internal entailment relations between the two silos could easily lead to $b \neq b'$, $b \in B$, $b' \in B'$, and $B \neq B'$, which represents the discrepancy between the original plan and the results of the plan execution when the environment presents a change, $a' \neq a$, $a \in A$, to the system. The top-down performance measurement function represented by $\hat{b} : \Phi \to f$ in (b) of Figure 6 may add more performance standards for the team, but it will not be able to alter this siloed practice and its consequence. Fundamentally, it is the existence of the silos under the machine model that makes it necessary to impose extra "business alignment" this way.

Only the replicate function represented by β in (c) of Figure 6 organizationally connects the operations and strategies as a whole by developing reciprocal and complementary interactions discussed in previous session, as shown in (b) of Figure 5. Under the organic entailment structure, the team now becomes a contributive resource to the strategic management. As a result, the management is able to develop better strategies and development plans that fit better into the changing environment. In return through this active interactions, the team will gain much better understanding of the strategies and plans.

[11] [Goranson, 2003] and [Hammer, 2004] reported similar issues. [Hammer, 2004] also recommended an iterative and incremental approach proposed by [Iansiti, 1997 and 1998] to address these issues.



(a) The improved machine model represents an organizational hierarchy, which may only offer business calibration from top down.

(b) A top-down measurement system $\hat{b}$ will not alter the organizational hierarchy.

(c) The replicate function β in the M-R model internally generates organic entailment counterbalancing the rigid organizational hierarchy.

Figure 6. A hierarchical view of the M-R systems

(a) of Figure 6 also illustrates that the hierarchical nature associated with the machine model may only allow mechanical calibration between the two silos. (c) of Figure 6 demonstrates that once the replicate function represented by β establishes the organic entailment of the M-R model, the relations between the management and the team becomes interactive and mutually complementary. The introduction of β will flatten the otherwise rigid organizational hierarchy under the machine model. The organically aligned enterprise is then strategically ready for proactive change management. In a sense, the organic alignment as shown in (c) of Figure 6 is a given under the organic model through congruousness between the three bio-functions.

Please note, by adding the map $\hat{b}$ to the entailment structure, (b) of Figure 6 further illustrates that the M-R model and the tool ABD do not necessarily exclude discussions on other relations existing within or between enterprises. One of the very purposes of these Rosennean tools is to help us reveal the fundamental drivers and limiting factors for enterprise development, which are otherwise hidden behind all types of material or physical considerations, organic or not. With these tools, the discussions are not limited by any tangible or intangible means that implement the relations in question. Once the organic entailment relations are established, as Rosen pointed out, additional causal relations that produce more internal entailment will actually strengthen the organic being. However when the organic entailment is missing, machines will always be machines, no matter how many more connections, material or digital, are added to the system, as shown in (b) of Figure 6.

As an overall result from the organic enterprise development, an eventual convergence between the development program and the subject enterprise will be reached. Since all parties actively participate in the development, their activities and results are intertwined together in the relational terms to grow the subject enterprise through one life cycle after another under the development program. The growth of the participants can be hardly separated from the growth of the subject enterprise, which will all interdependently become part of the evolving development program. Let E represent an organic enterprise development program, and B_l is the subject enterprise B that is going through the lth life cycle under E. Then the following equation can be obtained

$$\lim_{l \to \infty} B_l = E \tag{25}$$

where, l – the sequential number of development life cycles of an organic enterprise B under the development program E, $l = 1, 2, \ldots$

Or, when l is large enough, Equation (25) can be written as, with l removed,

$$B = E \tag{26}$$

In other words, the operations team, the enterprise management, and the physical or digital enterprise will eventually become inseparable from the organic development through enterprise life cycles.

(25) and (26) also indicate that the benefits of an organic enterprise may not be immediately seen before it has gone through a few of change life cycles. The short-term financial performance indicators may not

be able to differentiate organic enterprises from those inorganic ones, especially in industry where typical life cycles of physical enterprise constructions last as long as 2 to 4 years.

<Fluor information and discussions on "Total Values of Organic Life Cycles" are to be added here. We need more information to back up the data. We can still come up with a formula to estimate the benefits of organic approach if we don't have a complete case yet, since Fluor started PERA implementation about 10 years ago. What are the operating costs during 20 to 40 years to support the organic organization? Is that true that the operating costs are higher than those of machine organizations? What if we also have an estimate for about 10 years? What kind of improvements or changes will happen to the organic enterprise during the long time if we compare it with a machine enterprise? >

The impact of different development models also inevitably extends to the practices in information systems development. Under the machine model, since the underlying assumption is a given environment with little unknown changes, the development will mainly focus on the right systems specifications and then enhancement of the efficiency of the systems and associated development processes, which means more automations will be justified to enhance performance efficiency.

Under the organic model, since the top concern is proactive and anticipatory development in a changing environment where limited information will be available, the development should first focus on facilitating the interactions and communications between all parties involved to prepare an organizational infrastructure for effective and efficient change management. Automated developmental traceability throughout a single life cycle as well as across different life cycles should be valued to assist the needed change management. The scalability and flexibility of systems architectures are critical to the ability of organically iterative and incremental growth to allow the systems developers to pick and choose as needed. A management and control information system, when it is key to the performance management of an organic enterprise, has to be developed iteratively and incrementally so that it can evolve together with the organic business model. Within an organic organization, there is no excuse to develop the critical systems by following the machine model. For the same reason, technically iterative and incremental development is an inevitable result of being organic. Otherwise, the inorganic information system will become a limiting factor for an organic business system that it is associated with.

This holistic, therefore *all-inclusive*, approach is necessary for both Rosen's M-R model and PERA applied in the field of enterprise development. Although in this article mathematical diagrams and equations have been introduced to demonstrate the important concepts offered by the M-R model, the three bio-functions do not necessarily indicate exclusively computability or programmability for computers, as mentioned above. In addition to the non-computability stated by Rosen [Rosen, 1991, 2000], [Louie, 2004a] pointed out that the category *Ens* is sufficient to be a candidate objects of the M-R systems, and *Ens* does not dictate any computational requirement over the internal structures of the objects in the M-R systems. To be algebraic, which includes relational objects, will be sufficient. This is one of the important reasons why the formalism of the M-R model is able to holistically present rich perspectives far beyond the common computability, or computerized models.

4. Summary

As Morgan pointed out, early systems theories "developed as biological metaphor in disguise." [Morgan, 1997, p. 39] Rosen himself studied the realization of his M-R model and came to a conclusion that a promising approach to the model realization would probably lie in the identification of similar patterns from existing systems and then in return apply his system theories to "physics, biology, engineering or human sciences." [Rosen, 1971, p. 316]

The discussions in this article and previous one have identified the entailment pattern of the M-R model embedded within PERA life cycle. Comparisons between machine models and organic models following Rosen's definition have further demonstrated that for the purpose of enterprise development, the machine model may only represent a single perspective of machines, which can be considered a simplified case of the organic model. More importantly, if it is followed blindly where an organic model is actually needed to cope with a changing environment, the machine model will most probably lead the development process right into infinite chase after unattainable business sustainability where there is no effective solution to get out, though the seemingly promising automation can still be deluding. Such limits embedded in the

machine model can only be identified under Rosen's relational theories, his M-R model, and his mathematical tools of category theory.

Once applied to enterprise development, the replicate function in the M-R model represents organic growth function of enterprise management. It also represents organic business alignment that closely connects business strategies with enterprise operations. Following the organic model, the human and organizational development should not be treated the same way as machine development, and neither should the enterprise development. Although an iterative and incremental development may not necessarily be Rosennean organic, it is indeed one of the necessary conditions for an organic development. The full organic potentials of an enterprise must be grown from within and developed jointly by the management and the operations team so that the their enterprise can be strategically ready for a changing environment. An organic enterprise as such will become an effective and efficient incubator and facilitator that lead to sustainable strategic growth.

In the relational terms of A-R causal framework, an organic enterprise is an individual institution where strategic development and associated executions become a coherent whole based on institutional and mutual relationships between management and operations. Ultimately, to follow such an organic growth model or not is a business decision made by management. It does not mean the loss of leadership at all. The path of Rosennean organic growth is however not for people who are not willing "to persist for the long haul, those who like to rest on their laurels, those with no core ideology, and those who do not care about the health of the company after they're gone." [Collins, 2002, p. 245] Unfortunately, people who fall into this category may not be serious investors of strategic technologies either.

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