

## Knowledge Generation in the Enterprise Using Information and Data Systems

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**Abstract.** Many systems help us increase our knowledge of the world in one way or another. Business application systems help managers understand the marketplace and how best to address market needs. Military systems provide command and control capabilities so we can have better battlefield awareness so we can fight to win. Chemical processing facility systems help us gain awareness of what is happening all along the processing chain. If all these systems help us gain knowledge of the world, does SE have the tools to analyze the knowledge-creation capacity of our systems? This paper will explore that question.

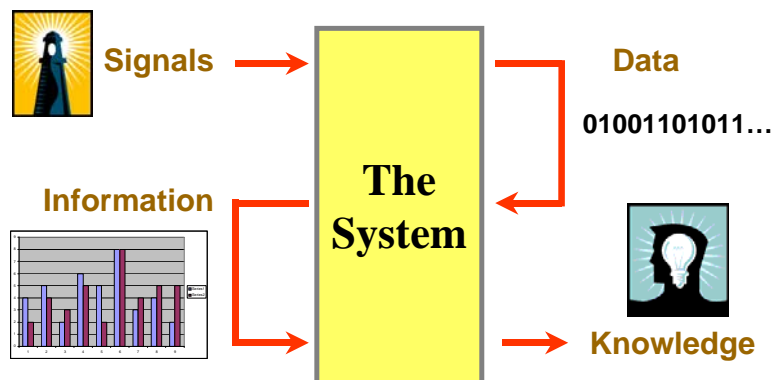
**Keywords.** Engineering systems, enterprise architecture, knowledge, information

### 1 Introduction

Most of the systems we develop are designed to generate information. But they also generate knowledge whether that was the intent or not. Is this knowledge valid and useful? Is it perhaps invalid and dangerous? Did the system at Three Mile Island generate the correct knowledge needed for that situation? Knowledge is needed for action. Wise and correct must follow. Poor knowledge often leads to incorrect (and sometimes dangerous) outcomes.

#### 1.A Systems Analysis of Knowledge

Systems engineering needs to recognize knowledge as an important system output. How often does it actually show up on our system block diagrams? Perhaps we need to expand our SE toolkits to include knowledge modeling, analysis and evaluation techniques.



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The measure of the “value” of a system is often a strong function of the knowledge it generates. From a systems perspective, we need to assess and evaluate the attributes of knowledge consumed and/or generated by a system.

- 1) Correctness
- 2) Timeliness
- 3) Accessibility
- 4) Truthfulness
- 5) Accuracy
- 6) Certainty
- 7) Adequacy

Often it is best to look “beyond” the system itself and instead look at the enterprise that contains and uses the system. I will explore the nature of enterprise architecture as it relates to system architecture.

### *1.B The Knowledge Challenge*

*Where is the Life we have lost in living?*

*Where is the wisdom we have lost in knowledge?*

*Where is the knowledge we have lost in information?*

T.S. Eliot, "The Rock", Faber & Faber 1934.

Systems engineering is highly dependent on information and knowledge. Ten challenges to the implementation of systems engineering and management were outlined in [1]. Three of these challenges deal directly with the need for better understanding of the knowledge-related issues in an organization:

- (1) Access to and utilization of information and knowledge
- (2) Information and knowledge requirements
- (3) Information and knowledge support systems

The challenge of access to and utilization of knowledge is that the proposed enterprise solutions “seldom address the basic issue of what information users really need, how this information should be processed and presented, and *how it should be subsumed into knowledge* that reflects context and experiential awareness of related issues.” [ibid. p1189, emphasis added] Part of the issue is the assumption that “more information is inherently good to have.”

What users should do with this information and how value is provided by this usage are seldom clear. The result can be large investments in IT with negligible improvements of productivity (Harris, 1994). One of the major needs in this regards is for organizations to develop the capacity to become learning organizations (Senge, 1990; ...). ... *Information is only a means to gaining knowledge....* Understanding and supporting the *transformations from information to knowledge* to advantage are central challenges to enhancing information access and utilization in organizations. [ibid., emphasis added]

The purpose of this paper is to address this challenge for the enterprise and its managers to gain a better appreciation for the knowledge needs of their organization and the knowledge-generating capacity of systems used by their organization.

## 2 Background

### 2.A Enterprise Architecture

Enterprise architectures gained popularity when John Zachman developed his framework for dealing with large information systems. [2, 3] These frameworks originally focused on data processing using mainframe computers, so their emphasis was on the data aspects of a business. Later, there was an emphasis on information processing in the business. [4-13]

In the past decade there has been an increasing interest in “knowledge management” since it has been recognized as a key ingredient in the success of businesses today. [14-21] However, most architecture frameworks in use today still have a focus on the data or information aspects of the business and little if any treatment of the knowledge aspects.

#### 2.A.1 The Information Revolution

There is talk of being at the cusp of the “third wave” where the first wave was the Agricultural Revolution and the second wave was the Industrial Revolution. [22] The third wave is the Information Revolution which started with the advent of computing technology in the 1950s. According to Pollock,

The decisive factors of production have shifted. In the past, land and capital were the dominant factors of production. Today, knowledge (of patents, processes, formulas, skills, technologies, customer information, and materials) is as important to businesses as land and capital were two hundred years ago. [ibid. p10]

The world we live in today is the product of a half century of living through this Information Revolution. Information technology has become a commodity while information itself has become ubiquitous. We now have at our fingers access to more information than used to be at the hands of research librarians. This creates a special problem for businesses in sifting through all this information rapidly enough to glean the essential competitive advantage before other businesses beat them to it. In 2002, there was enough information generated to provide each person on the planet with 800 megabytes of information. [ibid. p16]

#### 2.A.2 Information Overload

In response to this information explosion, businesses are “driving the evolution of software to support data and semantics together—which is actually the beginning of information.” [ibid. p17] Software and information systems have been designed mostly based on discrete logic and discrete information. More often the business must deal with fuzzy logic and fuzzy information. “Humans deal with fuzzy logic very well. We can walk into new situations, find patterns, react, and adjust as we go without completely halting the entire communication process.” [ibid. p22] Information technology (IT) systems cannot deal with this. The challenge is how to integrate humans back into the IT processes so they can utilize their special skills in this new world of “knowledge-centric” activities.

Humans must be involved in the details of information processing because of the hands-on nature of “resolving data and process meanings.... [which] means that software will continue to answer the questions of how data gets processed and what it will do with the data—but it will not answer the question of *why* it is performing a given set of logic or *why* it should convert data this

way instead of that way.” [ibid. p22] Answering this question of “why” is one of the main purposes of the business-focused knowledge modeling technique that I seek to develop through this research.

## 2.B Knowledge Hierarchies

### 2.B.1 Data vs Information

Software systems can be viewed in two general categories—data-intensive and information-intensive. [23]

First, there are those systems that require only a user interface to a database, requiring *little or no business logic built into the software*. These systems can be called “Data Intensive.” Second, there are those systems that require users to manipulate information that might be distributed across multiple databases, and to do this manipulation according to predefined business logic. These systems can be called “Information Intensive.”

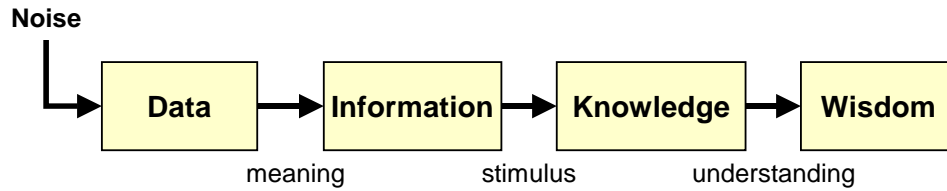
Data intensive systems can be built with reasonable ease through the use of 4GL [4<sup>th</sup> generation language] tools. In these systems, the *business logic is in the mind of the user*, i.e., the user understands the rules for manipulating the data and uses those rules while doing his work.

Information intensive systems are different. Information is defined as “meaningful data,” i.e., *data in a context that includes business logic*.... Data is the tokens that are stored in databases or other data stores. Information is multiple tokens of data combined to convey a message. Typically, information reflects a model. Information intensive systems also tend to *require information from other systems*.... Because of this, information intensive systems tend to be more complex than others, and require the most effort to build, integrate, and maintain. [ibid. p179, emphasis added]

Enterprise architecture development tends to focus on the enhancement of interoperability of enterprise elements. “Interoperability can only be achieved when information is passed, not when data is passed.” [ibid. p180] This is the reason for the emphasis on information systems and information technology to improve the efficiency of enterprise operations. [24-33, 6, 8, 23, 2, 13]

### 2.B.2 Continuum of Knowledge

There is not full agreement on the nature of knowledge. However, the representation below is commonly accepted as a basis for understanding the relationship between data, information, knowledge, and wisdom. [22]



**Figure 2-1. The DIKW hierarchy**

Consider the following example:

**Data:** 175

**Information:** The thermometer appears to indicate that it is very hot outside.

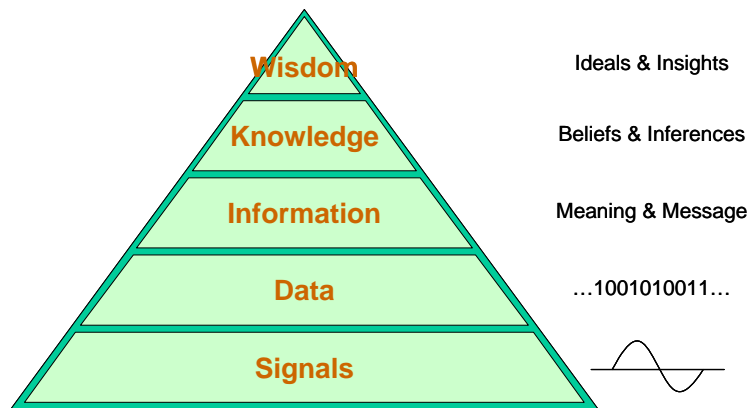
**Knowledge:** This is winter in Norway and it is not likely to be hot outside.

**Wisdom:** I should take my warm coat with me and get a new thermometer.

With semantics interoperability, “the expanded notion of data includes semantics and context, thereby turning data into information.” [ibid. p43] According to Pollock our current notion of software communication is broken. “We still tend to build software as though it existed in a closed world. These closed systems result in the construction of software that does not maintain links between data and shared, but usually implicit, background knowledge that is necessary for two or more partners to have the same understanding of the meaning behind shared data.”

### 2.B.3 The Knowledge Pyramid

To better understand the relationship between *Knowledge*, *Information* and *Data*, a “knowledge pyramid” was developed as part of my doctoral thesis research. [34-40]



**Figure 2-2. The Knowledge Pyramid**

Here, the *Signal* layer is added below *Data* to illustrate that often data is generated by collecting signals from the environment. There are often many “samples” of the environment to generate a single block of data. This data element is often an average or some other statistical measurement of one or more phenomena in the outside world. Each signal could be an aggregate of many different “things” in the environment. Likewise each “bit” of information is often generated from many bits of data, and each “bit” of knowledge is generated from many bits of information. *Wisdom* is added at the top of the pyramid to illustrate the ultimate use of knowledge in a business to provide good insights for decision makers.

There are various activities involved in transforming environmental phenomenology into wisdom.

- (a) Signals are detected from people, things or phenomena in the environment.
- (b) Data is converted from signals.
- (c) Information is extracted from data.
- (d) Knowledge is related from various sources of information.
- (e) Wisdom is discerned from knowledge.

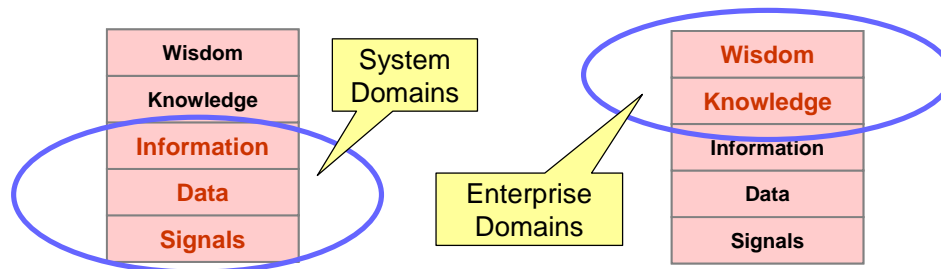
Space does not allow for a complete description of the Knowledge Pyramid. See [Martin06b] for a detailed discussion.

### 2.C Architectural Knowledge

An architecture is the bridge between the past and the future. It contains knowledge of the past (i.e., observations and trends) and knowledge of the future (i.e., predictions and prognostications). An architecture often contains decisions about the way things “ought” to be. Through these decisions the predictions are made to come about by the users of the architecture in their daily job of managing an enterprise or a system development project. In this manner, a manager can make “wise” decisions based on the knowledge contained in the architecture. This is what gives an architecture its value—its ability to enhance the decision making capacity of enterprise managers.

An architecture can be used to define the specific relationships between knowledge and other entities like information, data, business process, business managers, enterprise goals and objectives, organizational elements, and so on. The manager of a business needs to have some degree of knowledge of the “things” that are in the enterprise being managed. The planner for military activities needs to have some degree of knowledge of the elements of the battlefield, some natural (e.g., rivers and mountains) and some man-made (roads and weapons). An enterprise architecture can show the entities involved in an enterprise on which the enterprise knowledge is “dependent.”

Systems that consist of hardware and software primarily deal with the bottom three layers of the pyramid. There are special hardware devices called sensors that pick up signals from the environment. Other devices then convert these signals into data. Data is processed by hardware or software which generates information. Enterprises that consist of people, processes, organizations, facilities, goals and objectives, products and services primarily deal with the top two layers of the pyramid – Wisdom and Knowledge.



**Figure 2-3. Different domains for systems and enterprises**

Some architecture frameworks already have knowledge modeling constructs. For example, the Zachman Framework contains a “Motivation” column with entities such as business goals and business rules. These entities are capturing specific elements of business knowledge and using that knowledge to “drive” the organization in the right direction.

Some knowledge modeling techniques may be very accurate and precise in their modeling approach. But often in enterprise architecture activities, there is a tradeoff between fidelity (accuracy and precision) and ease of use (simplicity and clarity).

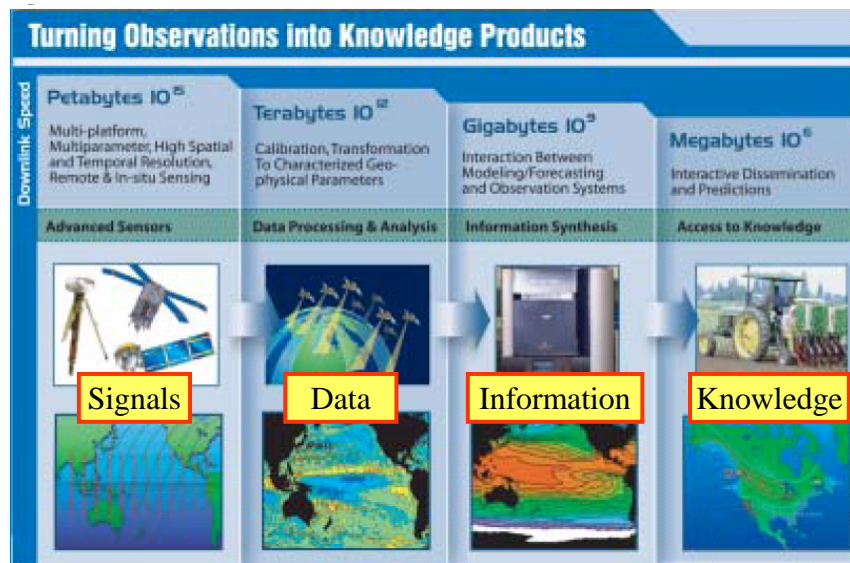
## 2.D An Example from the NASA Earth Science Program

This section describes an example of an enterprise architectures developed for NASA. This architecture spans the spectrum from signals to data to information to knowledge. The architectures were developed with a specialized knowledge modeling approach embedded in the Metis modeling tool. [www.metis.no]

### 2.D.1 Turning Observations into Knowledge

NASA has the charter to develop the means for exploration of space and to generate the scientific knowledge from space exploration activities. The NASA Earth Science program deploys spacecraft flying as platforms carrying sensors that pick up signals from various environmental phenomena. Petabytes ( $10^{15}$ ) of signals are turned into data by sensor-embedded algorithms. NASA and others develop models of the earth, its atmosphere and cryosphere, and the near-earth region that has an impact on the Earth.

These models extract useful information from the terabytes of data generated by the sensors and data processing devices. Scientists use this information to generate megabytes of knowledge in terms of new theories, technology attributes, and environmental characterization models. This flow from Signals to Knowledge is illustrated in Figure 2-4. [41]



**Figure 2-4. Turning observations into knowledge products**

### 2.D.2 Earth Science Enterprise Architecture

An enterprise architecture for the Earth Science activities of NASA was developed to assist in assessing the capacity of scientific instruments in meeting the needs of society. The architecture contains about 3000 elements that are involved in earth science research: observation sources, sensors, environmental parameters, data products, mission products, observations, science models, predictions, and decision-support tools. The science models use observations from the space-based instruments to generate predictions about various aspects of the environment. These

predictions are used by decision-makers around the world to help minimize property damage and loss of human life due to adverse conditions such as severe weather storms. Development of this architecture is described in [42].

### 2.D.3 Integrated System Solutions Architecture

The basic elements of the NASA Applied Sciences Program are connected in the manner shown in the Integrated System Solutions Architecture (reference model) illustrated below. The decision-support tools shown in this reference architecture are operated by NASA’s partners to make policy decisions and management decisions. For example, the Federal Emergency Management Agency must decide how to prepare for and mitigate the impacts of natural disasters such as hurricanes. The National Weather Service must decide when to issue a hurricane warning, and local governments must decide when to issue evacuation orders.

All of these decisions can have societal benefits in terms of millions of dollars of property loss averted and in thousands of human lives saved. These decision-support tools depend on having timely access to the right data, information and knowledge about the environment (and about the impact of human activities on the environment).

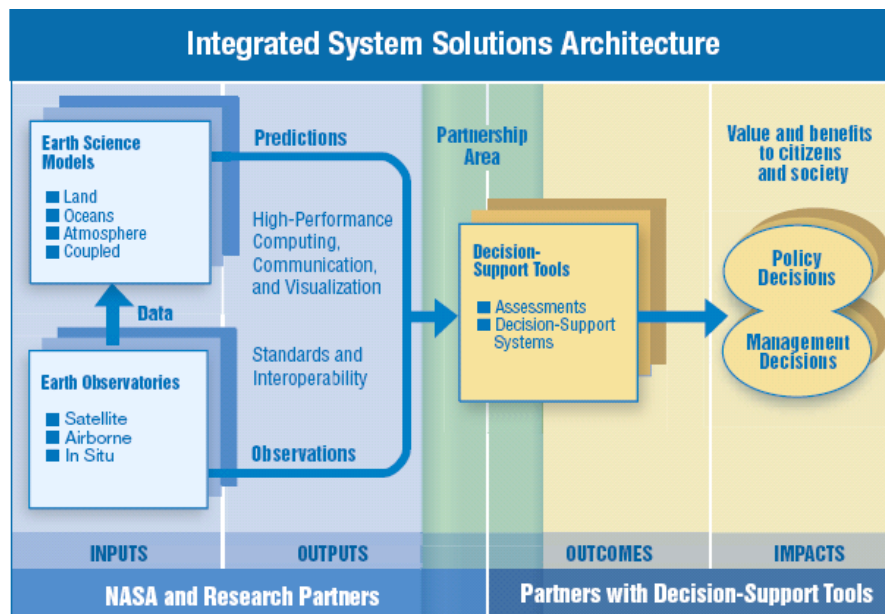


Figure 2-5. Integrated system solutions architecture reference model

We can map the elements of this reference architecture to the elements of the Knowledge Pyramid as shown in Table 2-1.

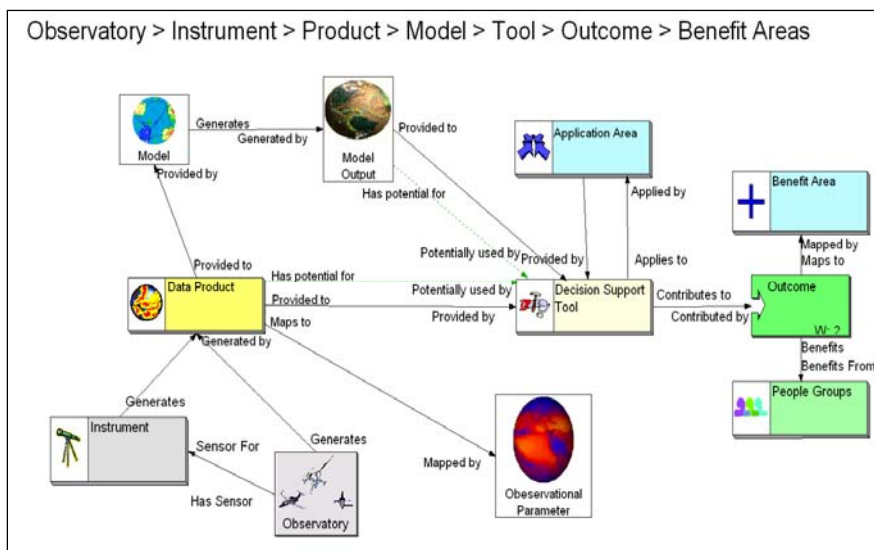
Table 2-1. Pyramid layers mapped to Integrated Systems Solution Architecture

	Earth Observatories	Earth Science Models	Decision-Support Tools	Decision Makers
<b>Wisdom</b>			<ul style="list-style-type: none"> <li>Tool operators apply “fudge factors” to correct for missing or misleading info</li> </ul>	<ul style="list-style-type: none"> <li>Discern current and potential future situations</li> <li>Discern best course of action</li> </ul>
<b>Knowledge</b>		<ul style="list-style-type: none"> <li>Use some observations to improve accuracy of</li> </ul>	<ul style="list-style-type: none"> <li>Relate information from various sources</li> <li>Display relations to</li> </ul>	<ul style="list-style-type: none"> <li>Connect various bits of information to get the “big picture”</li> </ul>

	Earth Observatories	Earth Science Models	Decision-Support Tools	Decision Makers
		models ▪ Calibrate models using reference data	decision makers	▪ Conduct trade-offs between different options
<b>Information</b>	▪ Extract info from data products (observations)	▪ Extract info from observations ▪ Generate predictions	▪ Ingest predictions	
<b>Data</b>	▪ Convert energy levels to data ▪ Generate higher-level data products	▪ Ingest data from observatory data products		
<b>Signals</b>	▪ Detect energy in the environment ▪ Detect variations from steady state			

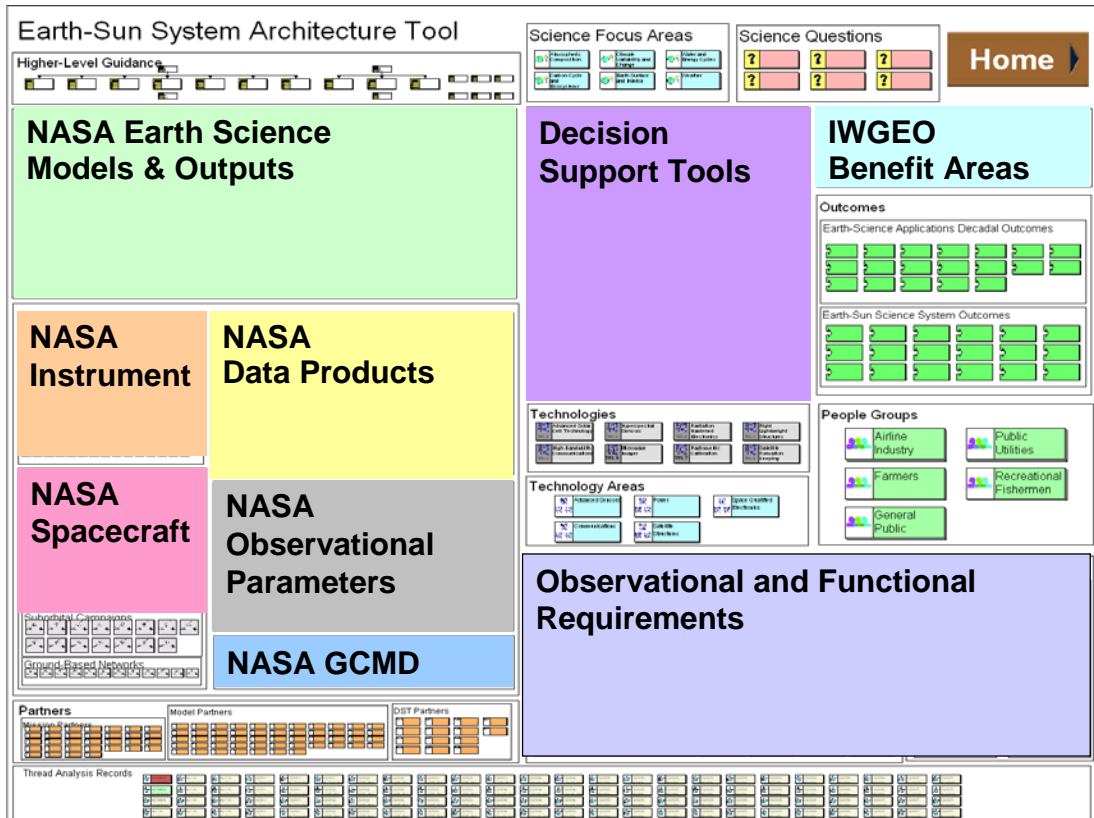
#### 2.D.4 Enterprise Architecture Development

The results of conceptual analysis of the problem were converted into a formal metamodel as illustrated below. Each of the entities in the metamodel represents something that needs to be “known” by the decision maker to help understand the complete picture of the current situation in the enterprise (the “as-is”) and of various possible future situations (the “to-be”). The metamodel prescribes the data (and data characteristics) to be collected for incorporation into the architecture model.



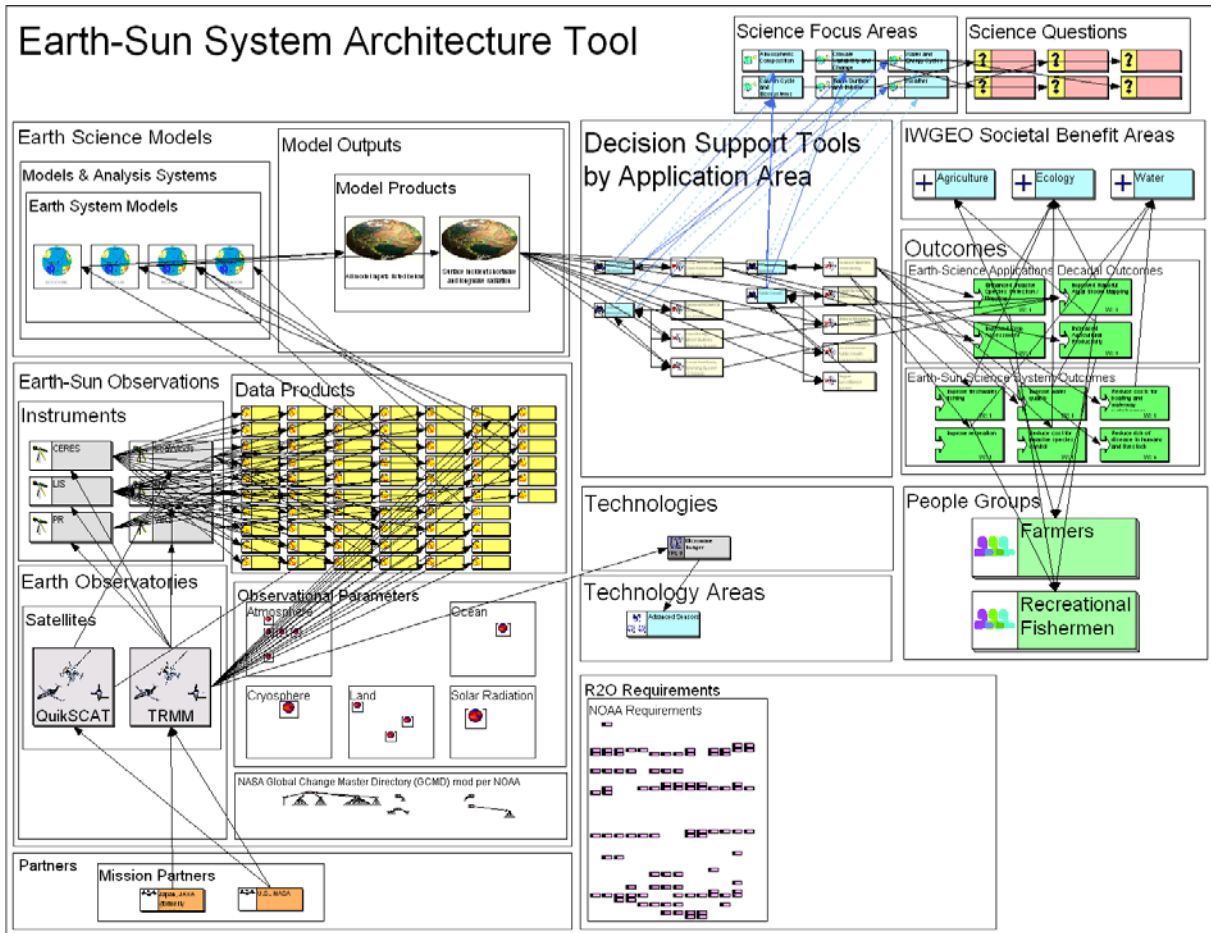
**Figure 2-6. Metamodel for Earth-Sun System Architecture Tool**

Data was collected by NASA on the 3000 architectural elements, and the architecture model was populated as shown below. The model includes 60 current and future spacecraft and 35 other airborne and ground-based observatories. These observatories contain 438 instruments that produce 471 data products which, in turn, feed into 241 Earth science models. The model outputs provide data for 28 decision-support tools.



**Figure 2-7. Earth-Sun System Architecture Tool**

The enterprise architecture can be used, for example, to identify the architectural elements relevant to the TRMM and QuikSCAT missions. The same information that would take a human analyst weeks or months to collect can be identified in seconds using the tool. A visual representation of the information is displayed by the tool (see Figure 2-8 below). This visualization greatly enhances the suitability of this information in addressing enterprise management issues and concerns. It makes it much easier to make business decisions and the quality of decisions is usually enhanced.



**Figure 2-8. Example of using the architecture to address management issues**

As you can see above, there are nine decision-support tools (DSTs) involved with these two missions. We can then determine the potential outcomes from making decisions with the DSTs and identify the expected benefits to society. The tool also addresses particular science questions as shown in the upper right in the figure above.

### 3 Conclusion

Knowledge-creating systems are becoming more important. [14, 5, 43, 21] We must move in this direction to handle the ever-increasing information overload of our society. [44, 39, 38, 15] Therefore, systems engineering needs to improve its toolkit so it can better handle this challenge. [45, 8, 27, 22] The field of enterprise architecture has been developing some of the requisite tools and techniques. [2, 24, 27, 8] We need to embrace enterprise architecture as a better way of seeing the “big picture” when evaluating our systems for suitability in the marketplaces of the world. [13, 26, 46, 11, 30, 32]

**Biography.** James Martin is a systems architect and engineer at The Aerospace Corporation developing solutions for information systems and space systems. Dr. Martin led the working group responsible for developing ANSI/EIA 632, a US national standard that defines the

processes for engineering a system. He previously worked for Raytheon Systems Company as a lead systems engineer and architect on airborne and satellite communications networks. He has also worked at AT&T Bell Labs on wireless telecommunications products and underwater fiber optic transmission products. Dr. Martin did graduate work at George Mason University in enterprise architecture and knowledge modeling methods and at Stanford University in engineering design. His book, *Systems Engineering Guidebook*, was published by CRC Press in 1996. Dr. Martin is an INCOSE Fellow and for eight years was leader of the Standards Technical Committee. He recently received from INCOSE the Founders Award for his long and distinguished achievements in the field.

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