Enterprise integration of product development data: systems science in action

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The work program of complexity (WPOC), stemming from systems science, was applied by a large cross-functional team of Ford engineers and system developers in the mid-1990s as an enabler to create an enterprise-wide information system known as the C3P system. This brief descriptor refers to a CAD/CAE/CAM/PIMS system, applied to design, engineer, and manufacture automobiles; and further to provide product information across and beyond the entire enterprise, extending into the supplier and customer base. The design foundation of the C3P system retains its utility today. The only system changes have arisen from technological upgrades which are independent of the original design strategy.

Keywords: Cross-functional teams; Enterprise information system design; Enterprise integration; Enterprise software systems; Project management; Systems science; Work flow; Work program of complexity

1. Science and technology in the computer age

As the late Geoffrey Vickers noted, science and technology have never advanced in lockstep (Vickers 1965, 1980, 1983), observing that ‘...throughout almost the whole of human history, technology has progressed with an uncanny ignorance of the scientific principles which were guiding it’. As an extreme example, he noted that the Japanese had magnificent steel as early as the 12th century, long before the science of metallurgy had any form whatsoever (Vickers 1980).

When technology leads, as in the computer age, it is inevitable, as has occurred, that practices not embedded in scientific foundations will evolve to a status of dominance. When this occurs, it is also inevitable that some time will elapse before these practices will give way to new practices founded in science.

Systems science depends upon technological advances for its empirical testing and validation because of the wide scope to which it pertains. For proper evolution of systems science a singular situation must arise where a necessary overlap of the evolving practice and the evolving science can take place. This overlap must occur at a point where the theoretical and methodological components of the science have

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been developed and tested to the point where the empirical side of the science can be tested in the cauldron of very significant situations. If such an overlap occurs at the right time, both the situation and the science will benefit. The science will be further developed; and the situation will achieve gains not likely to be found without the science and will, at the same time, provide a case study for future situations. This is one of the hallmarks of the development of any science and, in the instance to be described, of systems science.

A situation of this type arose at the end of the 1980s, when researchers at Ford Motor Company began looking into what was then called the science of generic design (Warfield 1990, 1994) and its supporting action component, then called 'interactive management'. Over time the systems science subsumed these concepts and extended their power in applications like the case study of the systems science presented here. The case study of the technical development and implementation of the C3P system itself is deserving of full expression but, in this paper, only the particulars of the use of systems science in this application are presented, in order to illustrate how future applications in enterprise integration can enjoy similar benefits.

In assessing the results of this work, one may use broadly three factors in intellectual productivity set forth by the late, and highly-respected, Kenneth Boulding (Boulding 1966), who argued that there were three principal reasons for poor intellectual productivity:

- **Unproductive emulation.** Which in our context could refer to the continued practice of developing information systems for a large enterprise without the discipline of underlying science.
- **Cultural lag.** Which in our context could refer to the failure to recognize what is available in the literature that provides a scientific basis for large system design.
- **Spurious saliency.** Which in our context could refer to proceeding without any scientific basis for assigning priorities among the very large number of possible action components in developing information systems in a large enterprise.

### 1.1 The initiative from the Ford Research Laboratory

In 1989, the first author undertook a study for his employer, Ford Motor Company, to determine whether there existed a science of design. It was part of the lore of the practical mind that such a science is impossible. There was also a theme running through much of the design theory and methodology literature at the time that design, because of its significant human component, was not something that lent itself to construction of a science. Nevertheless the search for such a science continued at Ford, until it was discovered that the second author was in the process of publishing the first edition of a very large book on system design (Warfield 1990, 1994). Immediately exploration was initiated to explore the potential utility of this work within Ford.

It was this initiative that eventually coupled the work on systems science to the needs of the cross-functional team charged with design and implementation of Ford's C3P system, beginning in 1995, and continuing to serve the company since its implementation.
2. Prevailing conditions in the automobile industry in 1995

In order to appreciate fully this case study of the design and implementation of a major enterprise system, it is necessary to understand the circumstances that prevailed at the time of its initiation in 1995. These circumstances are broken down into three parts: the industrial situation into which the system is to be embedded, the science that is to be applied to invent and implement the system, and the interaction between the industry and the science.

In many ways the context of the auto industry then is the same as today:

- strong global competition reflected in increasing market share of the Asian producers;
- demand by customers for high quality at a low price, e.g. good value;
- the need to produce new vehicle designs on a three-year or less cycle, versus typical 5-6 year cycles in the 1970s and 1980s;
- the need to reduce engineering cost by more efficient use of design resources;
- increased dependence on analysis and modelling and less on physical prototypes;
- the need to access and share product data rapidly across the enterprise, and with the supply base engaged in developing sub-systems and components for the car.

2.1 The industrial organization

The Ford Motor Company, to which this case study applies, and to which it is dedicated, found itself in 1995 in turmoil. It was struggling to increase its product development efficiency and found that, over many years, different parts of the organization had installed design automation software to increase local productivity (e.g., engine design, body structural design and exterior styling, and manufacturing plant floor design) in relative isolation. Now as the company looked to take engineering productivity to the next level, which involved sharing product information more seamlessly across disparate company functional units, it discovered that these multiple software systems were difficult to link together. Like most of the automotive industry, Ford was faced with the challenge of matching the complexities of transition from an analogue world of drawings and clay models to a digital world where product designs existed in the computer only with no physical presence.

The vision became clear: it was an absolute necessity to develop a comprehensive strategy that would enable sharing of product information across a very large organization, even extending across several continents. Accompanying this enterprise vision was a very large question: what methods or system of management should be used to create the means to accomplish this vision?

2.2 Ford Motor Company and systems science

In the late 1980s the co-authors of this paper, unknown to each other, were engaged in work that would ultimately come together to answer this large question. Staley was employed as a researcher in artificial intelligence in the...
Ford Research Laboratory. He had decided to explore the literature on design theory and methodology looking for foundational material to support knowledge-based systems design. Warfield had submitted a very large manuscript of a book on systems design to a publisher, who had agreed to publish the book. To learn more about this work and its possible application to Ford research activities, Staley contacted Warfield at George Mason University (GMU).

As a result of this initial contact, in April of 1991 Staley arranged the first of what was then called an 'Interactive Management Workshop' at Ford's Dearborn facilities. This workshop began the design of a system for digital design of vehicle power trains by integrating multiple, stand-alone, analysis tools. This three-day workshop, sponsored with some trepidation by Robert DeLosh of Ford, was the first application of interactive management (IM) in the Ford Motor Company.

Interactive management was the name given at the time to a collection of group work processes for large-scale system design that would evolve, partly as a result of a 16-year period of collaboration between Staley and Warfield, into something called the work program of complexity (WPOC). The latter is the action component of systems science (Warfield 2006; see pages 119–124 for a description of the Ford work). Since systems science has been described in relation to enterprise integration in a tutorial (Warfield 2007), only the specifics as they relate to the Ford case will be brought forward into this case study.

The April 1991 power train workshop at Ford was followed by numerous other workshops on a variety of topics until, in 1995, the opportunity came to support the design of the major system that is to be described here. It was because of the success of the previous workshops, and the fact that some of the key managers who had worked on the power-train team were also to be involved in C3P development, that Ford had acquired sufficient confidence in the systems science to accept it as the preferred means for carrying out the strategic design of its corporate-wide product development information system.

2.3 A C3P system

It is difficult to imagine an organization that would require more integration than a large automobile manufacturer in the waning days of the twentieth century. At the origins of its manufacturing operations are the suppliers of raw materials. These materials, meeting stringent functional and quality requirements are, in turn, used by other suppliers to fabricate automotive components and sub-assemblies which are forwarded to the auto companies' assembly plants. At the assembly plants, components and sub-assemblies must come together, each meeting stringent design requirements, to form the final working product.

The final automotive systems, consisting of three dimensional parts, separately supplied, if not meeting all the requirements, when put together, tend to violate the principle of physics that 'no two things can occupy the same space at the same time'. So a key concept of 'computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE)' that come together as C3, is to share the information that avoids that problem on an enterprise-wide basis.

Sharing this information, which is comprised of data on parts fabricated in different parts of the world, shipped to different parts of the world, dealing with suppliers in different parts of the world, with customers in different places, having
different desires, there must be a product information system to manage the information exchange process. Hence there must be a product information management system, i.e. a P. So putting this all together you have a C3P system, a large system, highly integrated, carefully designed, to serve a very large enterprise extending around the globe. This was the challenge facing Ford Motor Company in 1995.

3. The system to be designed

The system to be designed would be a collection of software systems all linked together and therefore integrated by data sharing protocols using what would be designated the PIMS (product information management system). A single CAD system was chosen (per the strategic design developed using IM) and this system was linked with CAM and CAE systems through data standards and protocols managed by the PIMS.

Design in the Ford environment has two meanings. The first meaning is the 'styling' or exterior surfacing of the car, which is done in the CAD system. The second meaning is the development of the geometrical description (in 3D) of a component or assembly using so-called 'solid modelling' software.

Engineering in the Ford system is the analysis, refinement and verification that a 'designed component' meets all its performance requirements. It includes many types of engineering analysis software (e.g. finite element analysis, multi-body dynamics, computational fluid and thermal analysis). Engineering is also concerned with meeting non-performance requirements such as cost, weight, and reliability.

The C3P system has unusual features that are not going to be found in many other industries. This typically means that the requirements are more stringent, but does not mean that the scientific base is inappropriate for other industries. On the contrary, the application of systems science most likely will differ only in the lowering of some of the values found for the various indexes of complexity.

Most industries could use a C3P system similar to the one described here. The architecture of the system would be seen as generic and applicable to a wide range of industries. The types of analysis software used in combination with the PIMS might be more particular to a given industry. For example, aerodynamic computations would be much more prominent at Boeing than at Ford, while cost and exterior styling would be more important in the design of the automobile than in the space shuttle. Every enterprise would benefit from ready access to product data in making the day-to-day business decisions required for systems engineering of intricate devices.

3.1 The status of the C3P system today

Before proceeding to describe how the C3P system was designed, it is appropriate to discuss the results of the design. Many Ford subject matter experts participated in the design, using IM with its two primary methods described in the references. The system implementation has been considered very successful. It is still in use today, largely unchanged in concept and application. While it is necessary to make changes
to the technical base of the system from time to time, the basic architecture and
strategic design remain intact.

The system design can be considered to involve two aspects: the strategy and the
technology. There has been no change in the strategy over the last decade. Only the
technology has been changed and it will continue to be upgraded to take advantage
of new developments in analytical techniques and available software. This means
that the strategy, as devised by the Ford staff over a decade ago, using the systems
science, remains inviolate today. It is because of this highly successful situation that
this case study is offered to systems designers, who may find it appropriate to return
to a scientific basis for systems design.

3.2 How the C3P system is used now

Implementation of the Ford C3P system started in 1996. It was first introduced in
new car programs and then spread throughout the product development organiza­
tion. The system is now used by the following groups: design, body engineering,
power train (engine, transmission and drive line), vehicle and package engineering,
interior styling, interior layout and test development, manufacturing plant layout,
work cell design, tool design, and assembly line development.

In addition, any group doing work that either produces product geometry or uses
product geometry to do other things uses C3P. Moreover, it is used by those who
develop service manuals and user manuals. In short, it is used over the entire life
cycle of product design, development, and service.

4. The six-component corporate C3P strategy

Efforts to conceptualize the C3P system begin at the corporate level. Early in 1995,
the corporate C3P strategy team found the following major issues descriptive of the
situation:

- Product information issues: Insufficient infrastructure and procedures to
  manage and provide timely access to product information, including changes
  in design and manufacturing throughout the life cycle.
- Technology issues: Insufficient coordination of corporate response to rapidly
  changing C3P technology.
- Work practice issues: Non-integrated practices inhibit effective processes and
  confuse suppliers, while limiting the mobility of internal creative resources.

In order to work toward the resolution of these issues, the corporate C3P strategy
team chose six strategic components (SC-1 to SC-6), which would drive future effort:

- SC-1. Enterprise integration: Enable integration of the global expanded
  enterprise—Ford people, processes, technology and suppliers—so that
  product information is available in the proper format where and when it is
  needed.
- SC-2. Process re-engineering: Support and enable continual process
  re-engineering to realize evolving new product delivery process objectives.
• **SC-3. Methodology:** Use advanced C3P methodology and functionality for competitive advantage.

• **SC-4. Product information management:** Achieve seamless information flow between CAD, CAM, and CAE environments through product information management (PIM).

• **SC-5. Software purchase:** Purchase C3P software from external vendor(s) whose objectives are aligned with those of Ford.

• **SC-6. Technology awareness:** Maintain strong awareness in emerging C3P technologies and integrate as appropriate.

5. The first handoff: the corporate implementation team

The first handoff of the corporate C3P strategy occurred in the first quarter of 1995. The early actions involved the use of systems science in the conduct of three IM workshops taking place in April and May of 1995.

These three IM workshops, forming a sequence on the same topic, have been chosen to illustrate the use of systems science in the design of an enterprise information system because, while other workshops were used in Ford to complete the system design, these three constituted the heart of the design. Following the description of these three workshops brief discussions of the nature of the others will be given. Please be advised that not all the work was done in the workshops. Some was done by highly-experienced staff in between the workshop sessions; e.g. computation of metrics, production of structural graphics, and preparation of interpretation reports.

6. The discovery component of the work program of complexity at work

In order to compare what was done with the systems science, it will be recalled (Warfield 2006) that systems science consists broadly of two sequential components: Discovery and Resolution. It would be expected that the design of the C3P system would reflect these two broad components.

Figure 1 illustrates the sequence carried out in the Discovery portion of the system design.

6.1 Box 1: Generating a problem set

Box 1 in figure 1 represents a facilitated group activity, in which one of the two methodologies contained in systems science (Warfield 2006) is applied to generate a problem set. The problem set is generated in response to a triggering question which, in this instance, was:

What problems are anticipated in implementing the new C3P strategy within Ford?
The members of the working team write their responses silently. Typically only about 20 minutes are required to write the responses. Following that, a typical time period of between 2 and 4 hours is required to write, post on a wall, and clarify all of the responses.

Immediately below Box 1 in figure 1, please note that the group members generated a total of 112 problems in response to the triggering question. This number is representative of what has been found over the years, perhaps slightly more than normal, but not unusual.

6.2 **Box 2: Filtering the problem set**

Perhaps the most fundamental means to support creative behaviour is to avoid criticism during the production of ideas. When the problem set is generated and clarified, it is almost invariably true that some problems are much more significant than others. Rather than query the group as to whether some are bad ideas, the positive approach is taken in the first of the two methodologies of systems science: the nominal group technique (NGT). Each individual votes silently on a card as to which members of the set are the five most important, and then ranks them. Aggregating the votes and tabulating, those that receive any votes at all are placed in a (filtered) 'most important subset'. Those that receive no votes are left for whatever later action may be elected. In this instance, 47 problems from the set of 112 received at least one vote, as indicated in figure 1, just below Box 2. By adding the scores, one can rank the 47 problems according to the total scores. This ranking has only the merit that if there is pressure to conserve group time, those that receive the highest scores can be given attention first. In this instance, 35 of the problems chosen from the subset were selected for structuring.

6.3 **Box 3: Structuring the problematique**

With 35 problems in the computer, the computer is programmed to present questions to the group in a sequence which is determined by the computer software, based on
the answers that are provided by members of the group. The software embodies the second methodology of systems science called 'interpretive structural modelling' (ISM) (Warfield 2006). A typical question presented to the group would appear as follows:

Does lack of customized training for different divisions and their related product/process needs (49) significantly aggravate limited time to identify and resolve software shortfalls prior to pilot (67)?

A question of this type will be discussed for understanding, and finally voted on. After the vote is entered, a new question appears on a screen for discussion and voting. Eventually, after the computer has received all the information needed to structure the problematique, the computer announces that it has completed its work, and makes available the information required to construct the problematique.

The personnel who have been operating the workshop will have printed the individual problems in large upper-case font complete with problem numbers for identification, and will construct the problematique on a wall in full sight of the entire team. Normally this will require about a half an hour, providing opportunity for study of the problematique by experienced staff who may wish to give a brief commentary on its structure after it has been posted.

6.4 Box 4: Computing complexity metrics with data from the problematique

With the problematique in hand, a variety of activities can be carried out to assist in interpreting it. Some of the activity will consist of computing a variety of complexity metrics. Such computations may or may not be done in the sequence indicated in figure 1. It may be, for example, that the work shown in Box 3 would be followed by work shown in Box 5.

6.4.1 Two types of complexity metrics. Complexity metrics can be computed for problems or for situations. The problems metrics help develop insights into how to categorize problems. The following categories have been used in this respect: Critical, Underrated, Overrated, Cyclic, High-Activity and High-Weighted. Placing problems in these categories, according to the scoring attained from the problematique, greatly facilitates discussing strategies for how to proceed with particular problems, helping to lay the basis for the second component of the WPOC—the Resolution component.

6.4.2 Scoring two problems. To illustrate a use of problems metrics, one instance is cited. As shown below Box 4, Problem 60 had an influence score of 39. This problem reads: 'Lack of formal structure and staff for the C3P implementation.' In examining this problem, it was placed in the class of Underrated. This problem ranked well below many others in the NGT filtering, yet it had the highest influence score. It is thereby flagged as very underrated. This is an example of how problem scoring yields insights not readily available when examining situations with very large problem sets.

Problem 67, showed a highly negative influence score of -32. This problem reads: 'Limited time to identify and resolve software shortfalls prior to major production vehicle pilot.' Problem 67 was tied in importance ranking (ranked 13) with Problem 60. Yet Problem 67 was aggravated by almost all other problems,
suggesting that there was little point in applying any resources directly to Problem 67, while Problem 60 had the potential to help ease the difficulties of many other problems. Problem 67 was in the High Activity class, but it aggravated nothing, and was aggravated by many things.

Problems 60 and 67 lie at opposite ends of the problematique [contact the second author for a copy if desired], demonstrating by inspection their distinctive nature.

6.4.3 Situation metrics. The other type of metric, the situation metric, provides macro interpretations, enabling persons who have engaged in multiple cases to apply insights gained by working across cases. As the data below Box 4 indicate, the problematique contains 508 relationships. This means that, on the problematique, there are 508 pairs of problems such that the first member in the pair aggravates (makes worse) the second member in the pair. This is a very large number, atypical of problematiques. The other situation metric, the SCI (Warfield 1990, 1994) has the value 7640. This is a very large value and can be compared to other published values, the smallest of which was 522 for a ‘direct engineering pilot project for air conditioning hose assembly design’ (Staley 1995).

6.5 Box 5: Placing problems in categories (dimensions) using ISM and discussion

The same concept (ISM) can be used for placing problems in categories. The question posed by the computer, in this instance, was:

‘Does Problem A have significant aspects in common with Problem B’?

Please note that only the relationship is changed from that used to develop the problematique.

Because this type of question is less definite and more judgmental than that used to develop the problematique, the computer product should be seen as a first draft. When it is put on the wall, in the form of what is called a ‘problems field’, the facilitator leads a discussion, which typically results in movement of problems from one category to another, and may even lead to the creation of one or more new categories.

When the categorization has stabilized, and only then, the categories are named. After that, individuals may or may not wish to place the problems that did not get put into categories into the categories on the wall, conceivably placing all 112 problems on the wall. Questions of this type are decisions to be resolved in situ.

The categories are also called ‘the dimensions of the situation’. One of the arbitrary decisions or discoveries, if you will, of the work at Ford, was to call the categories developed in this way the dimensions. This nomenclature fits nicely with what is known in systems science as Ashby’s ‘Law of Requisite Variety’. It states that the designer should enjoy the same variety of choice as the variety of what is to be rectified in the situation. This concept is embedded in the systems science, as illustrated in this case study.

Please note below Box 5 that the number of dimensions is shown as 12. Actually the number was first found to be 8, but as the learning proceeded, the number gradually was expanded and the number ultimately attained was 12. This number, interpreted as the dimensionality of the design was applied in working on the choice
of options (activities to be chosen to implement the C3P system). A feature of the WPOC is that it allows for constant amendment of results as the learning goes on in the process.

6.6 Delivering results

As the workshop continues, documentation proceeds apace. Intermediate results are constantly being set down and copied. Hence, while the first workshop in this sequence of three was held in the period 25–28 April 1995, a follow-up was scheduled and held in the period 16–17 May 1995. In addition to the work described briefly, the first workshop provided a task support structure, interpretation of the problematique based partly on the problem metrics, a discussion of a large problem cycle in the problematique (13 problems, each of which aggravates each other) and its significance, an identification of four major themes, and followup recommendations.

7. The resolution component of the WPOC at work

With the problem set, the filtered problem set, the problems field, the dimensions, the complexity metrics, and the interpretations in hand, the team reconvened to begin to apply the resolution component of the work program of complexity (WPOC). One should know that the terminology in use at that time was interactive management (IM). The change of terminology from IM to WPOC does not reflect any intention to put IM aside, but rather reflects three factors:

- Aging terminology. The IM terminology was chosen in 1981 and described in detail in 1994.
- Updated methodology. Significant additions have been made to the methodology since 1994, quite a few of which were as a consequence of and integrated into the work at Ford Motor Company.
- Updated terminology. It would be a mistake to use only the older terminology to describe what is known now; hence the term WPOC is used.

This does not mean that anything described as part of IM has been renounced, only that the new concept is its successor, amounting to amendment by addition. The group generates options to go along with each dimension in the problems field and, if options come to mind that do not match such dimensions, new dimensions are added. When the options generation is completed and the options are arrayed in dimensions with appropriate titles for the dimensions, the group is split into small teams (usually two or sometimes three), and each team works to construct options profiles; i.e. one or more options from each dimension, such that the collection of options chosen constitutes the team’s proposal as the corporate design for the C3P system to be implemented. Figure 2 shows that portion of the work sequence involving the identification and choice of a set of design options, collectively referred to as a design alternative.

After each group has completed its proposal, the groups present their proposals and discuss them. Experience shows that the proposals are never the same, but have much in common. Differences are worked out through discussion, and a composite proposal is generated.
The options chosen for the composite proposal are tasks to be accomplished. What must be done next is to formulate a work pattern. This requires determining a first approximation to when each task will start and when it will end; and the usual information contained in a work breakdown notebook, such as who will be responsible, who will be working on the task, how much will it cost, and what intermediate decisions will be required.

Given this overview, figure 2 can now be discussed in more detail.

### 7.1. Box 7: Generation of options

The team is familiar with the problems from the previous workshop, and now is asked to use NGT to generate options. The triggering question is:

**What are the options for resolving problems associated with implementing the C3P strategy within Ford?**

As seen below Box 7 in figure 2, a total of 313 options were generated. Notably, the ratio of options to problems is 2.79. That this ratio frequently exceeds 1 in IM workshops is part of the discovery made in developing systems science and is called the ‘creativity ratio’. Basically, it amounts to the discovery that when the WPOC is used in the manner described, it will usually be true that the number of options discovered exceeds the number of stated problems, sometimes by a wide margin, as in this instance.

Many believe that Ashby’s ‘Law of Requisite Variety’ is a key discovery in systems science, offering a remarkable connection between an analytical situation and a synthetic situation; i.e. between the description and the design. Be that as it may, this concept is incorporated in the WPOC work, through generating options for the subset of problems in each dimension of the problems field; in order to make up an alternative in a system design.
7.2 Box 8: Determining the interdependency of option categories

The next issue to resolve is that of dependencies among options. To achieve this, the experienced IM staff constructed a Type 2 structure, which involves working with higher level elements instead of individual problems or options. In this instance, the staff worked with clusters of categories, the group having previously placed the problems in categories and named the categories. Keeping in mind that options are generated in the same categories that problems are identified, the triggering question used to assist in determining the sequence in which tasks will be chosen was:

Is the choice of options in Category X strongly dependent on the choice of options in Category Y?

Once the structure of interdependency was determined, this structure became available as guidance to the small teams in the work they undertook next to choose options from the various dimensions.

Table 1 shows the clusters, as arranged with the help of the options field dimensions and the use of ISM. The ISM work showed that choices should definitely be made in the sequence: first, Cluster 4; second, Clusters 2 and 3 jointly; and, finally, Clusters 1, 5, and 6 as a cyclic group with mutual dependencies. Without this type of guidance, options might be chosen in arbitrary sequence, overlooking dependencies among the options.

7.3 Box 9: Three small teams form options profiles independently

The concept of options profile has been elaborated (Warfield 1990, 1994) and demonstrated by second-year undergraduates at the University of Virginia in describing their design projects. Such profiles were constructed in the C3P work and made for easy comparisons of the different designs produced by each group as represented in the options profile they generated.

<table>
<thead>
<tr>
<th>Cluster number</th>
<th>Options field categories in the cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B. Options for transition user resources</td>
</tr>
<tr>
<td></td>
<td>D. Options for support resources management</td>
</tr>
<tr>
<td></td>
<td>H. Options for culture migration</td>
</tr>
<tr>
<td></td>
<td>L. Options for on-going C3P implementation</td>
</tr>
<tr>
<td>2</td>
<td>A. Options for standard PIM (data model) infrastructure</td>
</tr>
<tr>
<td></td>
<td>E. Options for infrastructure planning</td>
</tr>
<tr>
<td></td>
<td>G. Options for C3P strategies planning</td>
</tr>
<tr>
<td></td>
<td>K. Options for C3P financials</td>
</tr>
<tr>
<td>3</td>
<td>C. Options for bridging software functionality</td>
</tr>
<tr>
<td>4</td>
<td>F. Options for start-up of C3P office</td>
</tr>
<tr>
<td>5</td>
<td>I. Options for suppliers</td>
</tr>
<tr>
<td>6</td>
<td>N. Options for C3P plan risks</td>
</tr>
</tbody>
</table>
Three teams constructed profiles independently. This allowed groups from different parts of the enterprise to bring different perspectives to the design of the C3P system. Notably, each team chose approximately the same number of options.

### 7.4 Box 10: Reporting, comparing, and choosing an alternative

With the availability of large wall spaces, and the convenient displays of option profiles, it is easy to see immediately how the design choices of three small groups compare with each other; where they are alike, and where they differ.

Each group has a reporter who reports on the choices that a particular team made, explaining why those choices were agreed upon.

The large displays and very readable options profiles make it easy for a facilitator to monitor a group discussion aimed at arriving at a consensus options profile. As a result, differences were resolved and a single alternative profile was chosen.

The Red Team chose 32 options, the Blue Team chose 34, the Green Team chose 35, and the final profile contained 54 options.

### 7.5 Box 11: Arraying the options in the 12 dimensions

The chosen collection of 54 options is arrayed in the 12 dimensions for easy viewing. At each step in the work, time must be allotted to assure that nothing is lost from what has been accomplished, and that accurate documentation is preserved, before moving on to a later step in the sequence.

### 7.6 Box 12: Reporting to the task sequence group

In this instance, the task sequence group is the same group that did the options work, but in other instances, it might be a different group.

### 8. Developing the work breakdown plan

Now that the problems have been identified and clarified, the options for resolving them have been studied and clarified and a subset of options has been formulated and chosen as the preferred design alternative, the time has come to develop a work breakdown plan.

For this purpose the chosen options are now considered to be tasks to be carried out. Figure 3 begins with the products developed as portrayed in figures 1 and 2, and continues the process of designing the C3P system.

### 8.1 Box 13: Generating task start sequences

In using ISM to generate task start sequences, the following triggering question was installed in the computer:

Should work on Option A definitely be started before work on Option B (or should they start at about the same time)?
The choice of relationship is prone to misinterpretation by those who are not familiar with the mathematics, but this is not the place to go into the details of that, which requires considerable discussion. In any case, with this relationship, it is possible to know about the relative start times of tasks.

8.2 Box 14: Generating task end sequences

To determine task end sequences, the following triggering question was used in the computer ISM program:

Should work on Option A definitely be completed before work on Option B (or should they be completed at about the same time)?

This phrasing allows for uncertainty in answering, as does the interpretation of 'yes' and 'no', as explained in the description of ISM (Warfield 1976).

8.3 Box 15: Constructing DELTA charts for tasks

With both start and stop relationships known for tasks, it is possible to lay out common charts such as Gantt charts, or to produce more sophisticated charts such as DELTA charts, for which the acronym is described in figure 3.
8.4 Box 16: Preparing a work breakdown notebook

The large charts that reveal the logic and sequencing are not intended to show all the detail, hence the DELTA chart is, in essence the outline of a work breakdown notebook, which can be prepared to supplement and provide the fine structure for the overall program.

The collective documentation resulting from the activities of the WPOC, including the DELTA chart and the work breakdown structure, constitute the design of the C3P system in much the same way as the assembly and component drawings, along with the manufacturing process plan, constitute the design of an automotive door-latching mechanism. The options profile is the blueprint of the design. When sequenced and resourced, this design is then realized. Gasparski (1984) defined design as 'conceptual preparation for change'. The WPOC, rooted in the systems science, enabled the Ford C3P design team to deliver the conceptual foundation for an enterprise-wide change in the way Ford created and shared product information across the global enterprise.

9. Summary and conclusions

The essence of the C3P design, and the process by which it was created, have been captured in the foregoing. Following what was done, as described, different functional areas of the enterprise determined what had to be done in those areas to implement the C3P system. The strategy of introducing the system first with new car programs, where legacy data requirements were minimal was used, and proved very workable. That was followed by introducing it into existing car programs, where often existing data had to be converted for compatibility with C3P data standards.

As touched on briefly, the system has been in use since it was introduced in 1996. The strategy has never received further questioning (which is very rare throughout the family of enterprises as well). Normally in the typical strategy there is constant churning, as things do not mesh well due to complexity-induced under-conceptualization in the design.

Recently the underlying CAD system is being changed and it is likely that analysis tools have been added and upgraded over time as new capabilities are available. However, they have all to come into C3P being compatible with the PIMS to really work as part of the system. The PIMS defines how all software components must integrate into C3P. High quality conceptual design enables long standing stable system implementation.

The WPOC was defining in determining the system design. The C3P work was the first and only design exercise at Ford in which complexity metrics were used in the selection process for final system strategic design content. There are many reasons for this. Perhaps the key one is that the C3P joint team was composed from multiple camps (each represented by a pre-conceived preferred design solution) forcing that team to fully develop three system designs. The complexity metrics were used as one dimension of many in the trade-off analysis from which the final form of the strategy emerged.
Acknowledgements

Systems of enterprise scope and impact are likely to be successful and durable only when the many factors required to bring them into existence and manage them afterwards are successfully handled. Some of the factors in this case were:

- The farsightedness of the sponsor of the work that produced the system design.
- The availability of systems science and the accompanying WPOC.
- The talent and content knowledge of Ford subject matter experts who participated in the design and implementation processes.
- The ongoing dedication of the large team of Ford people who have used the system wisely after its implementation.
- The wise management of the system implementation and of the ongoing use of the system after its design.

The main factor considered in this paper is the second of these, connecting the system design to the use of systems science. The other factors have also been handled successfully, and a large cross-functional team of Ford engineers, managers, and system developers (far too numerous to name) can take abundant credit for that. As a further point of interest and evaluation, the authors dare to suggest that the readers may wish to check to see if the C3P system is still in enterprise-wide use at Ford Motor Company after another decade elapses.

References


