The acquisition of a System of Systems is just a simple multi-phased parallel-processing paradigm[1]

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Abstract. **Much research effort is being expended in an effort to develop new concepts that can be used to solve the problem of managing Systems of Systems. This paper shows that from an information and knowledge management perspective the system and software life cycle (SLC) for a single system is a multi-phased time-ordered parallel-processing recursive paradigm that is little different from the uncoordinated ad-hoc evolution of a System of Systems. Hence, after providing the necessary coordination, information and knowledge management based tools and techniques may be used to control the SLC of each of the individual systems in the System of Systems as well as the System of Systems itself.**

I. INTRODUCTION

The term System of Systems in its permanent sense [1] has come to mean a set of interdependent systems evolving at different rates, each at a different phase of their individual System Life Cycles (SLC). Controlling the evolution of a System of Systems is deemed to be a complex problem since the development and acquisition paradigm for even a single system is characterised by cost and schedule overruns [2,3], and project failures [4]. Thus much research effort is being expended in an effort to develop new concepts that can be used to solve the problem of managing Systems of Systems. This paper shows that the problem is not as complex as it appears, and is solvable at relatively low cost, if viewed from a different perspective.

II. ONE SYSTEM

Consider one new system within the System of Systems. The system development life cycle (SDLC) can be represented by Figure 1, which shows a sequential process producing the product. The system level requirements are the combination of the user's needs and external factors such as changes in technology, regulations, and other factors that effect the system. Since all systems being acquired interact with adjacent systems, some of the external factors come from those adjacent systems.

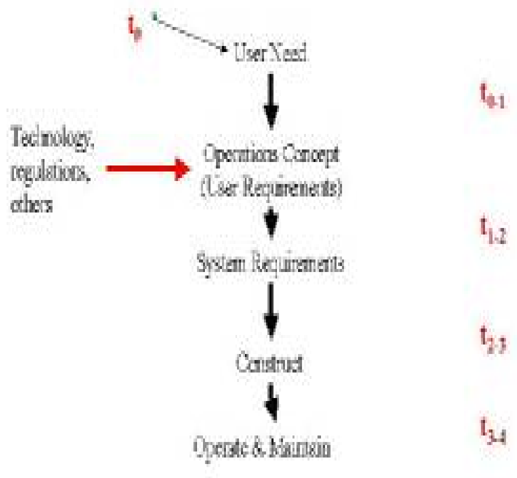

Fig. 1. The static system acquisition

However in the real world changes take place throughout the SDLC as well as the during the operations and maintenance phase of the SLC as a result of internal and external events. This situation may be represented as shown in Figure 2.

III. THE EXTERNAL PERSPECTIVE

Consider the system within the context or framework of its adjacent systems. The context diagram is shown in Figure 3. The system has an interface with several other systems but not necessarily all the systems in the framework. The temporal perspective of the evolution of the same set of systems within the framework is shown in Figure 4. Each horizontal line represents an evolving system. The implementation and delivery of such systems and software are often performed in partial deliveries, commonly called "Builds" in which each successive Build provides

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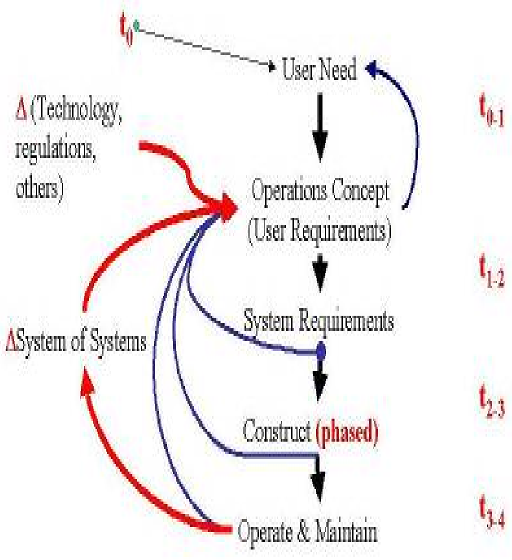

Fig. 2. The dynamic system acquisition

additional capability [5]. Thus the sequential blocks in Figure 4 represent the operational phase of the different Builds within the individual system's SLC. The SDLC phases of the Build have been abstracted out to simplify the figure. Lines begin when new systems are brought into existence, and terminate when existing systems are decommissioned.

This is the same representation as that for a System of Systems. **The difference being that the System of Systems is evolving in an ad-hoc uncontrolled manner.** Thus controlling the acquisition of a System of Systems is a matter of identifying the framework for the System of Systems and then managing the evolution of every system in the framework making optimised decisions for the framework as a whole. This is the standard systems engineering methodology for any set of subsystems in a single system. So from this perspective, three problems need to be solved to solve the System of Systems problem, namely

1. Develop a cost-effective SDLC for a single system that

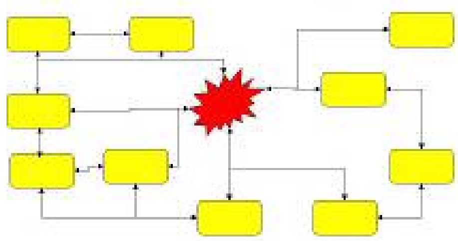

Fig. 3. Framework for the System of Systems

- can take into account the ongoing changes in adjacent systems,
- meets the customer's requirements as stated when the project starts,
- meets the customer's requirements as they exist when the project is delivered, and
- is flexible enough to allow cost effective

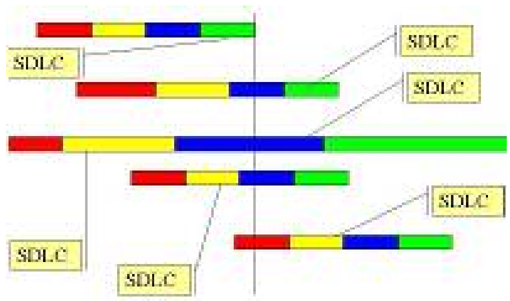

Fig. 4. Evolution of the Framework

modifications to be implemented as the customer's requirements continue to evolve during the operations and maintenance phase of the system life cycle [6].

2. Implement the links between the systems so that changes in the adjacent systems are taken into account in the evolution of each of the systems.

3. Provide the management information system to make optimal decisions for each system and well as the System of Systems [7].

IV. THE COST-EFFECTIVE SDLC FOR A SINGLE SYSTEM

The Cataract Methodology [5] with its focus on configuration control and knowledge management can produce systems that converge with the needs of the customer with fewer cost and schedule escalations and project failures provided appropriate knowledge management and configuration tools are used. The

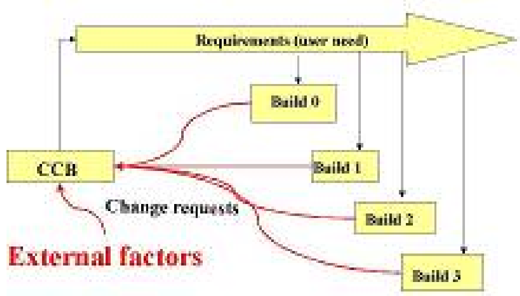

Fig. 5. The Cataract Methodology

Cataract Methodology is summarised in Figure 5 and is based on

- The recognition that the "Build" approach used in the operations and maintenance phase of the system and software development for software maintenance is also applicable to the development phase.
- The process for managing change during the development and operation phases of the SLC is the same process as that used for managing the initial set of requirements.
- The recognition that the SDLC is a multi-phased, time-ordered, parallel processing paradigm. The Cataract methodology recognises that evolution takes place throughout the SLC. Changes take place as a result of external factors as well as internal factors (changing customer needs).
- The criticality of configuration management and the information needed to control the production processes.

Therefore if the Cataract Methodology is applied to every individual system in the System of Systems **and** to the System of Systems as a whole:

- The SLC of each of the systems will be managed in a cost-effective manner.
- The interface for links between the CCB of each and every system will exist via the "external factors" input element.
- The evolution of the System of Systems as a whole will change from an ad-hoc manner to a coordinated manner.

V. ANOTHER PERSPECTIVE ON THE SYSTEM OF SYSTEMS

A combination of Figures 4 and 5 is shown in Figure 6. Each of the individual projects has its own CCB operating as described in [8]. Figure 6 shows a Strategic CCB (SCCB) operating in a similar manner to the CCBs for the individual systems. The SCCB interfaces to all the systems within the System of Systems and also has an external interface.

A. The recursive system life cycle.

When Figures 4 and 5 were combined, the Builds were flattened into a series of rectangles and the CCBs brought out and shown as a circle. As such this drawing can be applied to the development of subsystems within any of the individual systems. All subsystems might be developed in-phase in some of those cases. However, the normal approach of completing one subsystem at a time and then integrating it to the others is a multi-phased activity.

The drawing may also be applied to the situation in which the System of Systems of one organisation is added to several Systems of Systems of other organisations. Thus from the perspective of this drawing, the entire SLC is recursive and similar if not identical at any level but the lowest.

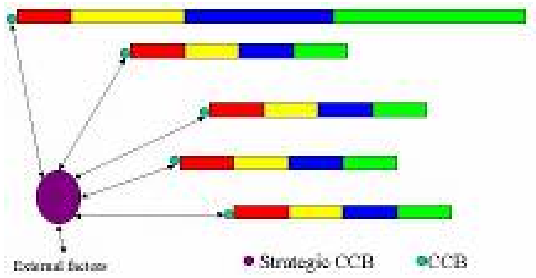

Fig. 6. Controlled Phased Parallel Evolution

B. Mapping the Architectural Framework into the organisation.

If Figure 6 is turned on its side, the traditional hierarchical organisational structure can be seen with the SCCB at the top. Thus from this perspective the System of Systems can be seen to be the same as the traditional system-subsystems configuration which can be mapped into the framework of any organisation of projects. However, when a mapping is made into an existing organisational framework

- The terminology used by the organisation and this paper will be different.

Fig. 7. The organization as a system

- The uncoordinated ad-hoc evolution of the System of Systems will become apparent due to the broken, missing links and elements. In addition, extra links may become visible. For example, in many organisations the SCCB may not exist and individual CCBs may not have links to one or more external CCBs.

VI. FROM THE PERSPECTIVE OF SELF REGULATING SYSTEMS

Consider the issue from another viewpoint. An organisation, project or even an element in a sequential process is a system and may be represented as shown in Figure 7. The system turns raw materials (inputs) into products generating waste and profits (wanted and unwanted outputs). There is a control loop which determines what is produced and when[2], based on customer needs. The control loop embodies a delay. Now consider two systems in series, they may be any sequential processes, such as manufacturing and painting, or subsystem construction and integration. The two subsystems, connected by the production process and the control and status links, may be depicted as shown in Figure 8.

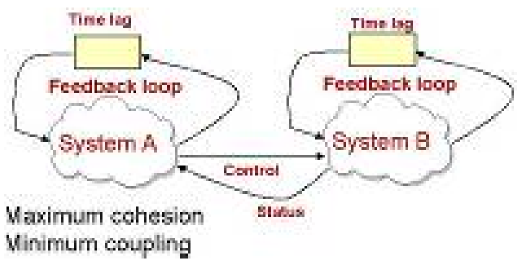

Fig. 8. Self-regulating systems

If the CCB control is added to the self-regulating subsystems, the arrangement becomes as shown in Figure 9. If the drawing is then expanded horizontally along the process dimension and vertically up the control dimension, and the control elements combined to optimise the span of control, the result is the conventional hierarchical organisation structure or system-subsystem chart [9].

Thus from this perspective as well, any current individual system acquisition can be considered as part of an uncoordinated ad-hoc evolution of the System of Systems of which it is a part.

VII. GAINING CONTROL OF THE SYSTEM OF SYSTEMS

Since any current individual system acquisition can be considered as part of an uncoordinated System of Systems life cycle, gaining control of the Systems of Systems is then a matter of

- baselining the existing System of Systems within a framework based on Figure 6,
- performing a gap-analysis to identify the missing elements,
- adding the missing elements to the organisation,
- developing the appropriate management tools suitable for both the individual CCBs and the SCCB,
- converting each individual system SLC to the Cataract Methodology,
- developing the transition plan, and
- implementing the plan using the Cataract Methodology.

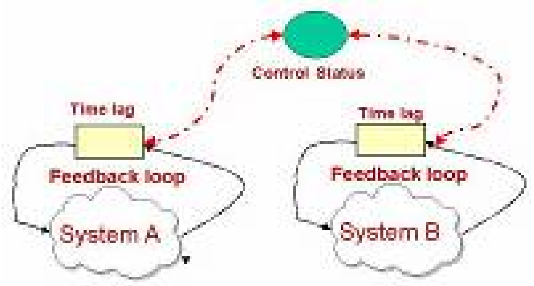

Fig. 9. Adding control to self regulating systems

The transition effort will probably be in converting to the Cataract Methodology and establishing communications paths between the CCBs of the individual systems and establishing the SCCB.

VIII. THE SUITE OF TOOLS

The suite of tools needed to control changes are a combination of several existing different and usually unconnected tools such as Requirements Management, Project Management, WBS, Configuration Control, and Cost Estimation, used in the management and engineering paths of the SLC. The Quality System Elements [10] for each system and knowledge based tools should provide the capability for a CCB to manage the acquisition of a single system in a cost-effective manner. The recursiveness of the SLC means that the suite of tools should allow the SCCB to manage the acquisition of the System of Systems in a cost-effective manner. In addition the tools should also provide the capability to perform

- impact assessments of the effects of proposed changes before implementation,
- trade studies on the costs and capabilities of alternative designs at the System of Systems as well as at individual systems levels.

Additional research needs to be carried out into the tools required for the SCCB as well as the degree of abstraction needed to avoid information overload.

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[2] This control loop may be broken in some organisations as a result of poor management.

IX. SUMMARY

While managing System of Systems is a complex problem in an industrial age paradigm, when viewed from an information and knowledge management paradigm, the problem is much less complex. By integrating Configuration Management across the process and product and using the Cataract Methodology to manage each system within the System of Systems, management of the System of Systems is achievable. However, the necessary information age tools are still evolving out of the current generation of project management, engineering and cost estimation tools.

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Joseph Kasser has been a practicing systems engineer for over 30 years. As well as being a Certified Manager, he has a doctorate in Engineering Management (Systems Engineering). He is the author of "*Applying Total Quality Management to Systems Engineering*", Artech House, 1995, and many conference papers. Dr. Kasser performs research into improving the acquisition process. He is a recipient of NASA's Manned Space Flight Awareness Award for quality and technical excellence (Silver Snoopy), for performing and directing systems engineering and has many other awards (certificates and plaques) as well as letters of commendation from previous employers and satisfied customers. Dr. Kasser also teaches systems and software engineering subjects both in the classroom and internationally via distance education.