A Structure for Systems Engineering Research

Timothy L.J. Ferris*, Stephen C. Cook*, Eric C. Honour#
*Systems Engineering and Evaluation Centre, University of South Australia
Mawson Lakes Boulevard, Mawson Lakes, 5095, Australia
Phone: +61-8-8302-3409, Fax: +61-8-8302-5344
timothy.ferris@unisa.edu.au
#Honourcode, Inc., 3008 Ashbury Lane, Pensacola, FL 32533

Abstract

This paper discusses the need for the development of a theoretical framework for Systems Engineering to facilitate recognition of Systems Engineering as a discipline and to provide a fundamental basis for advancing the practice of Systems Engineering. Systems Engineering concerns the development of systems that satisfy the real needs of those who call for the systems to be created. Such systems are not tangible things that can be analysed as objects to be inspected and described, but rather systems interact with their users and stakeholders in a complex manner, where the introduction of the system perturbs the pre-existent situation, resulting in a need for sophisticated methodologies to analyse and predict outcomes of system creation and deployment. The paper exposes and discusses a range of research methodologies that are appropriate for contributing to the development of a coherent framework of Systems Engineering.

Keywords: Systems Engineering research, Systems Engineering framework.

Introduction

This paper discusses issues associated with research in Systems Engineering and the status of Systems Engineering as a discipline. The questions of research and the status of a field as a discipline are closely linked in a manner that will be developed through the paper. The purpose of this discussion is to clarify the nature of the investigations that may reasonably be considered research in Systems Engineering and to discuss goals of research in the field.

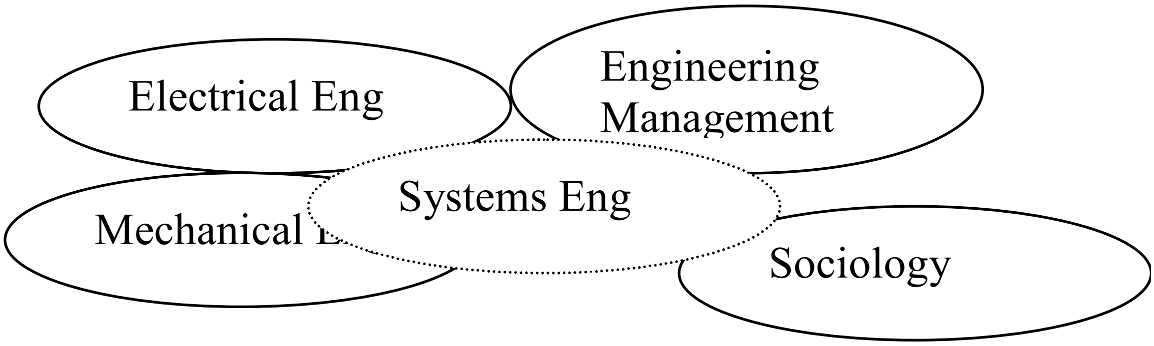

Figure 1. A representation of the study spaces claimed by disciplines and the problem of establishing and gaining recognition for a new discipline.

Systems Engineering suffers from a problem of being perceived as an activity or a practice, rather than as a discipline, particularly in the perception of other engineers. Why should this be? In contrast to the other fields of engineering Systems Engineering is newer, and so suffers from the difficulty of needing to assert its place and contribution in a space already occupied by other disciplines, each of which has an established scope and possible claims to the part of the space claimed by Systems Engineering, see figure 1. In contrast to the other fields of engineering, Systems Engineering concerns a different kind of activity, less about the inner details of any kind of stuff, and more about the means to determine what should be made and the best methods of making it (Honour, 1999). This contrast of area results in practitioners of other engineering fields finding Systems Engineering difficult to comprehend, since it does not relate specifically to the delivery of any particular kind of stuff and the methods used are quite different. Another contrast of Systems Engineering with other engineering fields is that whereas the others concern phenomena described and analysed in a deterministic manner, and apply the methods of reductionism to ensure that difficult phenomena are made deterministic, Systems Engineering includes substantial proportions of its methodology designed to address problems involving ambiguity and uncertainty, and seeks through application of its methods to transform problems involving ambiguity and uncertainty into problems that can be addressed using reductionist and deterministic means. Systems Engineering also tends to describe many matters related to the management of large complex projects, but so far has not established a rigorous quantitative theory that is used to determine the activities performed under the name of Systems Engineering, unlike the place of mathematical theory in the other engineering disciplines (Honour, 2002). These contrasts show that Systems Engineering differs from other engineering disciplines in significant ways that result in misunderstanding of the nature of the concerns between practitioners of the fields to the extent that the practitioners in the traditional fields may not recognise the area addressed by Systems Engineering as a discipline.

The difficulty Systems Engineering has with being recognised as a discipline also relates to the nature of Systems Engineers' activities as they seek to develop their area. Many investigations into aspects of Systems Engineering have suffered from being precisely investigations into aspects of the area. Thus, many investigations into development of Systems Engineering have concerned the development of methods and tools for performing parts of the Systems Engineering task. As such, the development projects have, themselves been excised from the whole, and made tractable using reductionist methods that themselves remove the uncertainties and ambiguities from the investigation of the matter at hand. As a result Systems Engineering research has tended to apply the traditional methods of engineering research, seeking to find optimised methods for performing the task at hand, rather than to apply the rationale behind the existence of the practice of Systems Engineering in the development and growth of the field. This challenge has been overcome by Engineering Management, which has become recognised as an engineering discipline because its area of concern has been clearly defined, and is accepted as different than that of other disciplines, and the methodologies of both professional practice and research have been established, and have clear connection to methods that other engineers recognise and accept as engineering or scientific research. The struggle for Systems Engineering is that the area of concern is less clearly understood by other engineers, and the misunderstanding of the area of concern leads to the belief that Systems Engineering is encroaching upon the territory of other engineering disciplines, and that the methodology of professional practice of Systems Engineering is a blend of art and science (Rechtin, 1997), and a generally accepted Systems Engineering research methodology is yet to be established and universally accepted within the field.

This introduces another relevant contrast of Systems Engineering and the other engineering fields. The other engineering fields developed in association with related sciences, mainly mathematics, physics and chemistry, with the result that the engineering approach of taking action that effectively achieves desirable outcomes is, in the case of these other areas of engineering, based on the existence of a substantial science framework that enables the engineering area to function within a defined space and to make its distinctive contribution. But Systems Engineering is not founded on any particular science discipline as a practical application space for that science. Consequently, Systems Engineering does not have any over-arching theory or structure to borrow from anywhere else, and has so far not succeeded in developing such a science to associate with its activity.

This paper makes a contribution to outlining the task and potential goals of research in Systems Engineering.

Generic Needs of a Discipline

The concept of disciplines comes from the arena of academic study. With the growth in the total knowledge of people there has been a subdivision of former fields of study into narrower subsections of the former fields. This tendency is a natural consequence of the growth of knowledge resulting in the impossibility of an individual being able to comprehend all the works in the broad span of studies represented by one of the former fields. Usually a new discipline emerges as a subset of a former discipline that has grown large and has come to be recognised as having a natural subsection. It is difficult to establish a new discipline as the intersection of two previously separate disciplines, and most such attempts tend to be dominated by one and incorporate useful insights from the other. Such inter- or multi-disciplinary originated disciplines arise from the recognition that two or more disciplines may be able to contribute insights that are useful to the development of understanding of some matter. There is another, less honourable, reason for the subdivision of the broad fields into distinct disciplines. The founders of disciplines, historically, have tended to be people of considerable intellect, who have also been determined individuals seeking to define a separate field of endeavour in a space that distinguishes their activity from that of others.

Part of the distinguishing of a field of activity as a discipline involves establishment of a set of generic characteristics of the field that enable the founders to credibly claim to have a rounded system of thought and action that meaningfully stands separately from other areas. The generic requirements are a framework of ideas, a methodology, and an area of concern. This concept is illustrated in figure 2.

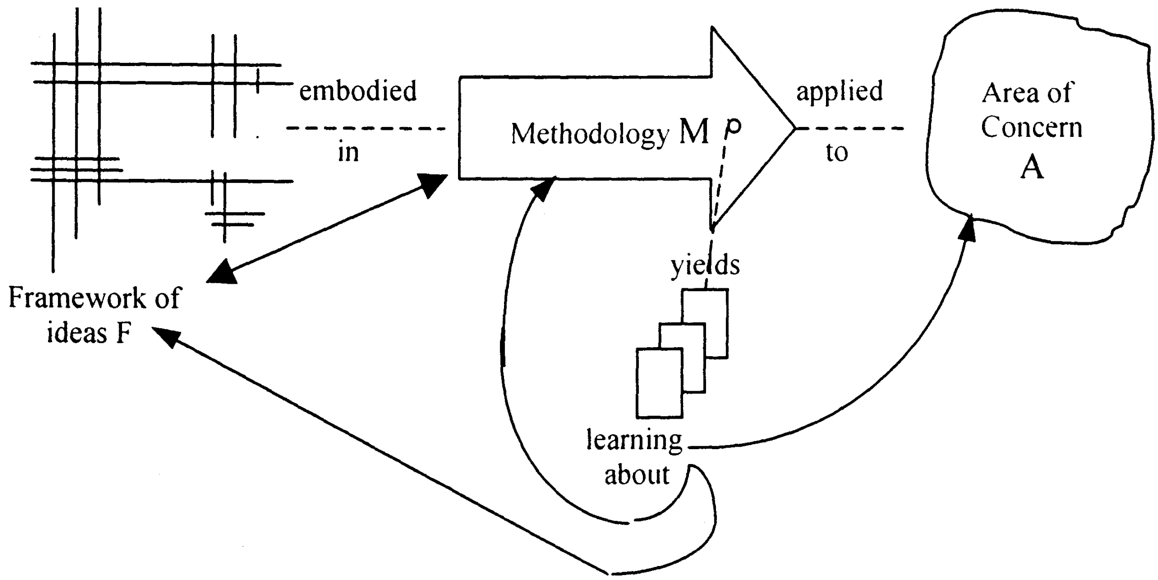

Figure 2. Checkland's Framework, Methodology and Area of Concern model of the generic characteristics of a discipline and research methodology. (Checkland and Holwell, 1998).

The framework of ideas is a coherent theory that makes sense of the whole of the discipline. The framework of ideas needs to be such that the theory spans the discipline in a single theoretical structure, not a collection of pieces that are not explicitly tied together. In addition, the structure of the theory needs to be made so that it is recognisably coherent, according to the standards of coherence generally accepted in diverse disciplines. Without a framework of ideas a field that claims to be a discipline is open to the accusation that it lacks the necessary structure to be explained and to provide a basis for the practice and application of the discipline to whatever class of matters for which it claims to be applicable. Put crudely, a field that lacks a framework of ideas will be regarded as 'lightweight' by participants in other disciplines, particularly those disciplines that claim to cover related application areas.

The methodology is a distinguishing aspect of a discipline. All disciplines have a method of performing the work of the discipline, both in development of the framework of ideas of the discipline and in the application of the discipline to appropriate matters. The methodology, as the means by which the discipline instructs that action should be performed, is derived from the framework theory as the appropriate means to perform work in the discipline. In many cases the methodology is a significant, obvious, distinguishing feature of a discipline, because method is what is visible and many disciplines have formed around the view of a founder that a different method to address a class of application than that offer by existing disciplines was required. Should a field lack a methodology it becomes powerless to do anything. A more common situation is that a field of activity claiming to be a discipline 'borrows' a methodology from one or a combination of other disciplines, and so opens itself to the accusation of being derivative and not really a discipline.

A discipline also requires an area of concern. Regardless of whether the purpose of a discipline is to explain a situation or to effect change in a situation it is necessary for a discipline to define a particular area about which the discipline claims to make pronouncements or effect contributions. Without some area of concern the field lacks the claim to do anything and so will lack power to persuade or influence with respect to anything because the field does not, itself, make a claim to be related to anything.

Systems Engineering as a Discipline

We now consider the position of Systems Engineering as a discipline with respect to the development of the three kinds of generic requisites of a discipline.

With respect to an area of interest Systems Engineering has been successful. The evidence of success is the considerable work performed in the development of systems, purely technical, human and technical, and socio-technical, which have addressed the needs of those who have commissioned the projects. The application of the Systems Engineering methodologies to the performance of these projects has resulted in an improvement in the success of the projects delivered measured against the traditional measures of performance, budget and delivery time. For diverse reasons, including shifting context and absolute ambition for system outcomes, the application of Systems Engineering methodologies is not a panacea that guarantees success, but rather a means to improve the probability of success. The major difficulty faced by Systems Engineering with respect to its area of interest is the over-use of the word 'system', particularly in engineering disciplines, that results in other engineers being confused about "what systems?", with the expectation of an answer like 'control systems' or 'refrigeration systems'.

Systems Engineering has also been successful in developing methodologies to address its area of interest. These methodologies take the form of standards defining process and tools that assist project participants in performing their roles in a manner consistent with the standards. The work on methodology has also included demonstration that the methods used have beneficial effects on project outcomes and are sensible methods for addressing the complexities introduced by large-scale projects. Systems Engineering has been less successful at developing methods for investigating Systems Engineering with a view to development of a theoretical framework for the field of activity.

Systems Engineering has a number of partial theories. These theories are partial because they address parts of the field, but so far there has not been a unifying theory that links all parts of the field into a coherent structure with a view to driving the development of methodology. The lack of a unifying theory is a weakness in the claims of Systems Engineering to be a discipline, largely because the status of a field as a discipline, is accorded by mutual consent within the academy, and all claimants must demonstrate possession of a framework to receive the recognition of others. However, as one pursues the goal of a theory of Systems Engineering it is necessary to question, as part of the investigation, the limits of any such theory. It is arguable (Hooker, 1992) that there is not, and cannot be, a theory of design. Since Systems Engineering involves the creation of designs of systems that satisfy objectives, it is reasonable to regard Systems Engineering as, in part design, and consequently potentially constrained by theoretical limits on the possibility of developing a theory of design. However, it is unreasonable to not attempt to develop a theory for that part of the field that is amenable to theory development for this reason. Therefore it is desirable to attempt to develop a theoretical framework for Systems Engineering that respects the fundamental limitations of such a theory, but pursues the development of theory as far as it is possible to go.

Purpose of Research in Systems Engineering

There are multiple purposes for research in Systems Engineering, which arise from the current state of development of Systems Engineering with respect to being a discipline. Since Systems Engineering is a field emphasising the pragmatic, the means to achieve success in projects leading to complex systems, the ultimate purpose of research is to improve the ability to deliver systems that satisfy the needs of the procurer. This has a number of aspects including means to define the systems that would satisfy the procurer's need, means to perform the system development, means to incorporate the diverse perspectives of contributors to the development process and means to maintain and enhance the capability of the supplier to develop future systems.

These grand objectives are large-scale things that are difficult to achieve directly. The usual approach to such a situation is to apply the reductionist philosophy that has served the development of the traditional sciences well since the Renaissance. The reductionist approach involves the definition of a portion of the task of a tractable magnitude, and sufficiently close to existing knowledge and observations as to be feasible for a finite duration project to address. The difficulty with the reductionist approach is that it accumulates a quantity of detail information that needs a second layer of analysis and investigation to create an overarching framework. To a considerable extent, this is descriptive of the current situation. Many projects investigating specific aspects of Systems Engineering have been performed and there is now a need to link the various project conclusions to create a framework. But 'link', above, does not mean simply to co-locate the results of all extant work in some kind of compendium, which would still present the sense of the field being a collection of pieces and lacking an over-arching framework, thus resulting in all the same criticisms as other could current direct at the field. Rather, 'link' is used in the sense of performing a further deep investigation of the issues presented by the diverse projects, and seeking to create a theory that puts the conclusions into the framework of a unified vision of the field.

The alternative to reductionist methods is to perform research that investigates the issues of the field from a holistic perspective, commencing with issues such as the goals and purposes of work in the field and investigation of the nature and characteristics of the challenges that the field faces. These challenges include such things as how systems can be defined in advance of design, facing the real issues introduced by phenomena such as customer expectation creep introduced through contextual changes and through the whole new revelation of what could have been requested that is stimulated by delivery of either the system or some intermediate delivery. This approach to research aims, in the first instance, to develop a framework for the discipline, and following this to obtain results that can be reticulated down to the more detailed matters of how things can and should be done.

Research Methodologies

This section is included to show that diverse research methods are appropriate for the development of Systems Engineering. Each of the research methods has been developed in other disciplines, across the whole range of academic pursuits. This is significant because the nature of Systems Engineering is different than the other engineering disciplines. The other engineering disciplines largely concern the understanding of things in a manner that enables the design of useful artefacts. This results in the appropriateness of methodologies of research that are closely related to those of the physical sciences, in particular experimentation to test hypotheses. The difference in the research of the sciences and engineering disciplines is primarily in the detail of the hypotheses that are tested, which in the sciences concern understanding the nature of things in and of themselves and in the engineering disciplines concern identification of the useful relations of things to other things and conditions. Since Systems Engineering concerns how systems are defined and developed there is a considerable interest in matters other than the tangible stuff of the systems. It is therefore reasonable to expect that different research methodologies are appropriate for investigation of the matters of interest in Systems Engineering. Six other methods are introduced below: scholarship, positivist hypothesis testing, applications driven research, action research, and case studies (Jackson, 2000).

Scholarship

Scholarship is the research process that emphasises the understanding of the body of literature in a discipline. Consequently, scholarship type research involves considerable reading of the existing literature of the discipline and analysis of this literature in order to identify themes and structures of the discipline that only become evident through the performance of deep thinking about existing knowledge. In addition, scholarship involves the relation of the discipline to other disciplines the application of insights from other disciplines to the particular discipline at hand. These processes are primarily book related.

The goal of scholarship is to develop new insight out of the existing body of knowledge of the discipline, and through this to produce enhanced understanding of the appropriate future directions for the discipline to pursue.

The danger of scholarship is that it may become introspective and separated from the concerns of real practitioners of the discipline because it may excessively build upon existing publications, of varying quality and validity and thus may be led along unfruitful paths by particular existing sources.

Scholarship is a primary research methodology in the humanities and some social sciences but is rarely used in the physical sciences and engineering. The principle use of scholarship in the sciences and engineering is in the review aspects of project presentation, in which the relation of the present work to the tradition is elaborated. This use of scholarship is also found in the project funding application process, in which proposed work is related to the existing body of knowledge and justified by showing that is addresses a gap in the existing knowledge. This use of scholarship is a secondary approach to research, being limited mainly to the justification of work proposed, rather than being the primary method of the research as it is in some fields where scholarship is heavily used.

Scholarship in Systems Engineering is growing to a significant stage of maturity, justifying the claim that there is sufficient scholarship to build a discipline. For example the University of South Australia library now holds over 300 title relating to Systems Engineering.

Positivist Hypothesis Testing

The positivist hypothesis testing approach to research relies on the development of hypotheses that are then tested by either experiment, where a state of nature is manipulated to test the effect of a certain perturbation, or survey or data mining methods, in which an existing state of nature or data about an existing state of nature is interrogated in a manner that tests a hypothesis about that state of nature. The hypothesis testing method of research has become deeply associated with the concept of 'science' and is now regarded as the principal or even the only method of research that is acceptable in true 'science'.

The purpose of hypothesis testing is to test ideas, embodied in the hypothesis, against real experience. This is important to ensure that knowledge is governed by reality, and avoids the disconnection from reality that is possible in the scholarship approach to research. The assumption underlying hypothesis testing is that observation of real things involves randomness and that therefore observed phenomena are known in a statistical manner. The result of this assumption is that one establishes an hypothesis about a phenomenon that enables observations to be made that could possibly disprove the hypothesis. The outcome of such investigations is that particular hypotheses are either disproved, being demonstrated false, or are not disproved with a certain measure of statistical significance. Hypotheses that are not disproved are regarded as supported, to the particular statistical level indicated by the statistical test processes, and are then regarded as statements of the nature of the reality observed.

Hypothesis testing presents several dangers. The outcome, the new knowledge believed to be obtained through the process of research, depends on the hypothesis that is tested. Should the hypothesis have been rearranged in some way, possibly in an apparently small grammatical change, the new knowledge obtained may be quite different. The result is that the hypothesis formulation stage is critical to the value of the research work, and should an unsuitable hypothesis be proposed the research output will be less valuable than desired, or even useless (Leedy and Ormrod, 2001).

A second danger is that the hypothesis must be testable by some process that can be implemented objectively and, in principle, by a third party. This presents the difficulty that research questions may be adjusted to become testable by the hypothesis testing method, and therefore reportable as scientific development, rather than constructed to provide insight into a truly significant, or important, phenomenon. This effect is seen in the many experimental or quantitative journal papers in which the conclusion of the paper is often a list of additional research topics that are the truly valuable areas for investigation that may have been excluded from the original work because of the need to construct a testable hypothesis.

Hypothesis testing is a pervasive method because it is the method that leads to the acceptance of work as 'scientific'. Since being seen as 'scientific' is a strong academic imperative of the present era the hypothesis testing method has been spread from the traditional sciences where it has a long established tradition and history of usefulness to the disciplines that seek to assert their status as 'sciences' rather than as some kind of 'art' other pejoratively perceived classification.

Applications Driven Research

Application driven research is work investigating the problems or issues associated with a particular application. Often applications driven research produces outcomes of more general applicability but the emphasis is on satisfying the driving purpose of the work, the finding of a solution to a particular matter of felt importance. In this case the matters investigated are derived from the needs of particular practitioners. This ensures that application driven research keeps in touch with the real problems of the world, and thus leads to enhancement of the practice of the discipline. The methodology of applications driven research is any method that is appropriate to discover solutions to the matter at hand.

The purpose of applications driven research is to improve the practice of the discipline. This goal is the consequence of the research form being the addressing of specific problems arising from practitioners of the discipline, whose normal interest is improving their practice.

Applications driven research addresses specific matters perceived by practitioners to be problems in the practice of the discipline. The result is that projects are likely to be structured as investigations to produce incremental improvement in some aspect of the practice of the field, rather than projects to provide a radical rethinking of some broad aspect of the discipline. The result is that applications driven research is likely to find local optimisations of practice, but is unlikely to identify and remedy any major defect in the discipline.

Action Research

Action research is a research methodology in which the investigator is a participant in the system or practice about which the research is focused. Action research concerns the investigator exploring the best way for the investigator to interact with the context with a view to effecting a certain kind of desirable outcome. Generally action research involves multiple rounds of iterative variation of action performed by the investigator and observation of the outcomes arising.

The purpose of action research is to learn the effect of actions of the investigator in the context in which they would normally be performed. In a strict sense, the results of action research are only applicable to exactly the situation in which the action was performed, but because of the similarities of that situation and many other situations in which the investigator may find himself/herself the major benefits of action research are found in the professional development outcomes for the investigator. This arises because the investigator learns to be more reflective in their professional practice, and consequently better placed to recognise and respond to situations, and also has a stock of considered experience to assist in recognition of potential outcomes of possible actions, which can then be applied in the decision to take a particular action. That is, the true purpose of action research is to build wisdom rather than to add to knowledge.

The action research methodology presents several dangers. Since the actions are those introduced by the investigator who is also an immersed practitioner, it is likely that the variations of practice introduced are modest variations on the theme of the existing tradition of the discipline. The result is that action research may not result in experimentation with radically different methods. In addition, since the variations introduced are generally those that can be effected by the investigator within a structure of work relationships it is unlikely that any of the variations of practice attempted are major changes of practice, since this would require approval and cooperation of others.

A second significant danger is to ignore the scope of applicability, and to seek to generalise from outcomes derived from a one-off series of experimental variations to a much wider range of times, places and contexts with the result that the generalisation becomes invalid. This effect is the cause of traditions developing in which people end up doing things that they do not understand why long after the original reason has been forgotten. The reason related to a specific context and people, and the tradition has made the practice normative for a wide class of future situations that are unrelated to the original context.

A third difficulty is ethical. Where a person makes considered changes to their behaviour, within the scope of externally imposed processes, for the purpose of improving their work effectiveness, such changes are part of good working practice, and are to be encouraged. But if the motivation for making changes is to obtain publications recording the changes and their effects, or to obtain professional development for the purpose of gaining a new position or some other private gain of the investigator there is an ethical problem because perturbations are introduced into a system that exists for some other purpose than this motive, and a conflict between the investigator's motive and the purpose of the system investigated may arise.

Case Studies

Investigators may seek to investigate classes of phenomena involving similar, but different, cases through a case study approach. In the case study method, the researcher obtains information about one or more particular cases of the phenomenon under investigation with a view to identifying similarities and differences in the facts of the case and in the outcome resulting. The case study methodology tends to be favoured in disciplines where the dominating focus is practice because the case study method holds the promise of identifying practices that are demonstrably effective in achieving the goals of the discipline. The case study method focuses on the practitioners and the practice, rather than the interests of the investigator, with the purpose of generating a theory about the field of practice that arises from the data obtained. The goal in the case study method is to generate a theory that arises from the data. In practice, many case studies stop short of generating a significant theory, usually because the authors recognise that the number of cases investigated is too small to create a sufficient database to generate a theory of statistically significant validity. The case studies that stop short of theory generation are justified as providing a further case data set for the benefit of those people who are in a position to perform a meta-case study, tying together all of the case studies in a particular field.

The case study methodology, like the action research methodology, may suffer from the attempt to generalise the results obtained beyond the valid scope of those results by transforming the descriptive into the normative. The case study methodology also contributes to the sense that a discipline lacks an underlying coherent theory because the case study method creates a body of detailed and specific observations, but does not connect the many observations into a coherent intellectual system. However, a coherent system may be approached through an appropriate overlay of scholarship over the case facts adduced through the study of cases and is the true goal of case study research.

The case study approach generates considerable data, and provides the opportunity to delve into ever-greater levels of detail. The problem with this is that the amount of data that can be accumulated is enormous, and can easily result in the investigator being over-whelmed by the data. If this occurs, the investigator becomes unable to see the structure of the matter for all the detail, and the study fails to generate meaningful conclusions, just a mass of data.

Conclusion

This paper has discussed the need for the development of a theoretical framework for Systems Engineering, in order that the field can grow in stature to be recognised as a discipline. Associated with the development of a theoretical framework of Systems Engineering is the need to create a methodology for Systems Engineering scholars to investigate Systems Engineering itself, as distinct from a methodology, which already exists, for Systems Engineering to perform its application tasks.

Although Systems Engineering has grown out of the engineering pursuits of people, and the pathway of professional development of many Systems Engineers is through one of the traditional engineering disciplines, Systems Engineering is different in kind to the other engineering disciplines, not merely in focus topic. Systems Engineering concerns the development of systems that satisfy the real needs of those who call for the systems to be created. Systems that satisfy real needs are not tangible things that can be analysed as objects to be inspected and described, but rather are systems that interact with their users and stakeholders in a complex manner, where the introduction of the system perturbs the pre-existent situation, resulting in a need for sophisticated methodologies to analyse and predict outcomes of system creation and deployment. In summary, Systems Engineering is the branch of engineering that concerns the development of 'equipment', not 'things', in Heideggerian sense of both 'equipment' and 'things' (Inwood, 1997).

Since the field of Systems Engineering addresses such a complex and multi-dimensional range of interests and concerns the methods of Systems Engineering cannot be analogs of the methods of the traditional engineering disciplines. A further effect is that the methods of research used in Systems Engineering should not be limited to the range of methods normally employed in engineering research. Rather, there is a need to develop a methodology for Systems Engineering that appropriately incorporates all the kinds of research described and discussed above to develop a unifying theoretical framework of Systems Engineering and to develop the disciplines self-examination and development processes, as well as the processes for the development and delivery of complex systems.

The result is that Systems Engineering is a discipline that is structured internally as a meta-discipline, linking, using appropriately and applying knowledge and methodologies from a wide diversity of other disciplines, including both traditional science and engineering fields and areas not traditionally associated with engineering, such as the social sciences and humanities, in addition to specialised knowledge and methodologies associated with the particular system development areas of concern that the meta-discipline is used to address. This is expressed in figure 3, which is itself an adaptation of figure 2.

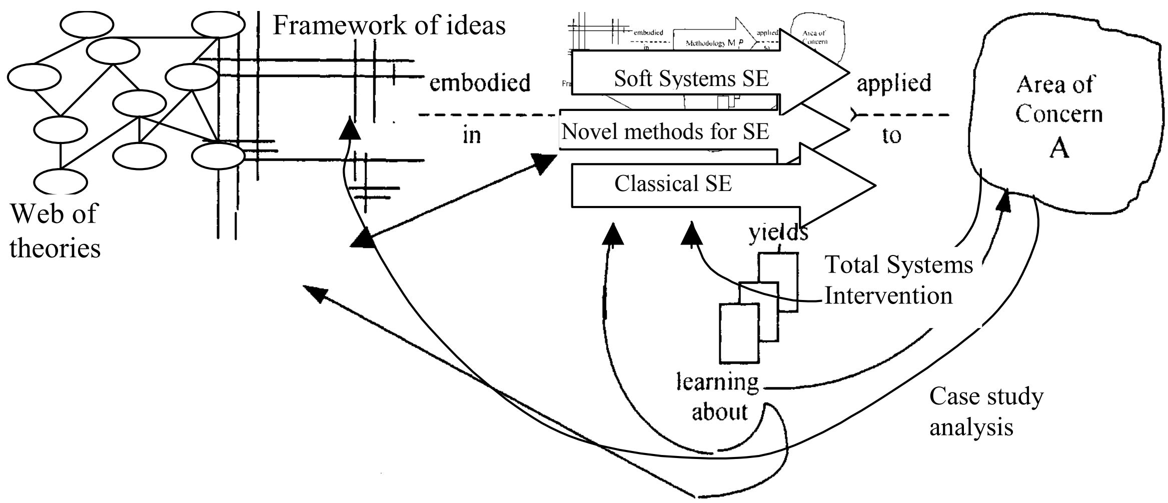

Figure 3. Diagrammatic representation of Systems Engineering as a meta-discipline, built on the simpler generic model of a discipline.

References

Checkland, P., Holwell, S. (1998) *Information Systems and Information Systems: Making Sense of the Field*, Wiley, Chichester.

Honour, E.C. (1999) Characteristics of engineering disciplines, *International Conference on Systems Engineering*, Las Vegas.

Honour, E.C. (2002) Toward a mathematical theory of systems engineering management, *INCOSE 2002*, Las Vegas, 28 July-1 August.

Hooker, J.N. (1992) Is Design Theory Possible? (manuscript sighted).

Inwood, M. (1997) *Heidegger*, Oxford, New York, Oxford University Press.

Jackson, M.C. (2000) *Systems Approaches to Management*, New York, Kluwer Academic.

Leedy, P.D., Ormrod, J.E. (2001) *Practical Research: Planning and Design*, 7th ed., Upper Saddle River, N.J., Merrill Prentice-Hall.
Rechtin, E. (1997) The synthesis of complex systems, *IEEE Spectrum*, vol 34, no 7, pp 51-55.