Support Engineering in the Concept Phase of the Life Cycle

Government procurement agencies and contractors, large and small, make use of life cycle phases in order to impose some structure on their development, manufacturing, operation and support processes.

When developing a new complex platform the first of these phases, usually termed the 'Concept' phase or similar, is arguably both the most challenging and the most important.

Starting with what appears to be a blank sheet of paper can be disconcerting, but if the project gets off to a good start, then it has a much greater chance of eventual success.

This applies to Support Engineering just as much as it does to the overall programme.

In the paper below we examine the Concept Phase from the perspective of a Systems Engineering based Support Engineering programme.

The Purpose of a Concept Phase?...

Life cycle phases and systems engineering go pretty much hand in hand. Systems Engineering is about managing complexity and breaking a complex process down into defined stages is one mechanism (*of many*) by which that complexity can be brought under control.

This approach is therefore relevant to Support Engineering, a very complex methodology, leading to a very complex and critical product. This paper is the first of a series, addressing a Systems and Systems Engineering approach to Support Engineering, an approach based on the structure provided by ISO 15288; the international standard for *Systems and software engineering – System life cycle processes.*

The first thing we need to understand is just what is the purpose of a Concept Phase? The answer is that there are a number of purposes and a number of different outcomes that we require.

The very first step to be taken on a project is to define the problem or the opportunity that is its raison d'etre, to answer the questions; Why are we doing this? What is this programme for? What are we, ultimately, hoping to achieve? That is we have to start defining the project "requirements", albeit at a very high level.

We also therefore have to consider, in parallel, what potential solutions are available which will mitigate such problems or capitalise on such opportunities, and the two processes cannot be separated; the nature of the solutions available impact the nature of the requirement, at the very least they ensure that the requirements are set within the bounds of feasibility. To illustrate, there is no point stating that the operational need is to decontaminate battlefield casualties who have been subjected to chemical agents, within a 5 minute window. Whilst this may be highly desirable in operational terms, it is well beyond the bounds of any extant, developing, or even conceivable, technology today.

This is possibly one of the hardest tasks, because we seem to be starting with a blank sheet of paper, but if done well it will greatly facilitate a successful programme. If done badly, or not done at all, it will have a significant detrimental impact on the programme.

ISO 15288 refers to these as the problem space and the solution space, and they inform, and provide a meaningful context, for each other.

The processes we need to consider therefore include:

1. Developing and documenting a profound understanding of what the stakeholders need
   This forms the basis of any formal requirements, indeed it forms the basis of everything that we do from this point forward.
   Note the term stakeholder here, for complex systems there is inevitably more than one…

We need to recognise that that these stakeholder needs may be mutually exclusive, that compromises, trade offs, will be needed (an example that many will recognise is the need for a hugely capable, yet very cheap, solution)

2. Which implies that we need to know who all the stakeholders are so they can be engaged with, kept informed, etc …
3. We need to identify potential solutions that may meet the need.
   We must appreciate that the range of possible solutions may be very wide.
   The general principle at this stage is that we cast our net wide, that we have open minds and that we give due consideration to highly innovative, unconventional approaches. Keeping in mind the fact that our solution may be entering into service many years in the future.
4. We need to identify any constraints that may impinge on the programme and on the potential solution.
5. We need to select, from those available solutions, those which warrant further development (in the next phase, which I will refer to as the "System Level Development Phase" – equivalent to the UK MOD's Assessment Phase).
6. We need to prepare for the next phases in the life cycle, so we need to prepare plans, costings and of course some initial, formal, requirements, both system level Technical Requirements and a Statement of Work [SOW].
7. We need to initiate the process of developing potential solutions, these need to be developed to a degree that enables alternative approaches to be evaluated and traded. We need to determine which solutions are feasible (*from a technical, acquisition cost, through life cost* [TLC] *and programme schedule perspective*). We need sufficient detail to enable us to prepare high level requirements and we need sufficient data to provide the justification, or otherwise, for continuing the programme.
8. We need to put in place all the resources; people, tools, etc to support these processes, we need to define the methodology that we will be implementing during the Concept Phase and in the subsequent System Level Development Phase.

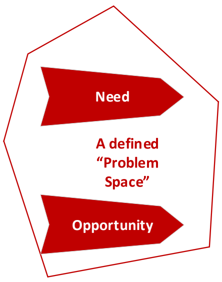
We need to create a report defining what we have done, what decisions have been made and why. i.e. we need to define a business case justifying our proposed solution and our proposed approach for developing that solution.

So, what does this mean in terms of Support Engineering?…

The first point is that the stakeholders needs, must be defined in operational terms, not in terms of the solution (i.e. "***We need to clear mines***", rather than "***We need a new mine plough***".

The earliest 'iterations' of the systems engineering process therefore focus on first defining the problem that we are trying to mitigate or the opportunity that we are trying to capitalise on, albeit at a high level. This is, in ISO 15288 terms, the "Problem Space". The aim is to use this information to support analyses and decision making processes that are designed to help us to select the optimal solution.

Now this isn't a dogmatic insistence that we don't engage in 'solutioneering' (*defining the solution without first engaging in appropriate analysis and contemplation of the options*). Operational needs can often be met in a number of quite radically different ways. To illustrate this consider the technical options that exist for dealing with land mines in all their variety. Options for mine clearing range from mechanical removal systems, there are various forms of mine ploughs, flails and lane marking systems for example, to hand held mine detectors and explosive lane clearing devices, such as Python.



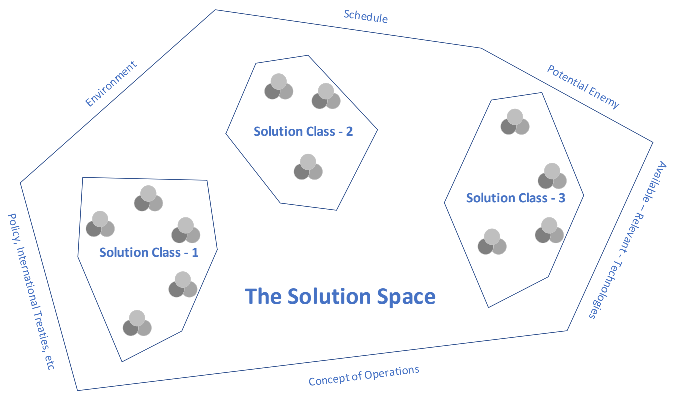
We have to define the problem in an unambiguous manner, whether our problem is how to address an operational need or how to capitalise on a new technology. The problem in itself may be complex; consider the example discussed below, the need to clear mines from a route to be used by men or land vehicles in a contested area.

The problem may involve detecting the mines, neutralising or moving them. This may need to be carried out in rural and urban environments, in a number of climatic conditions. The types of mines that need to be cleared may vary in type and sophistication, the process may be conducted frequently or infrequently. The enemy may be present (and trying to frustrate the clearance efforts) or not. The task may need to be conducted by small, fast moving foot patrols, or by large, slow, brigade sized armoured columns…

All this information needs to be captured, in ISO 15288 this is referred to as the "Problem Space", getting this right is critical, as it will of course influence the nature of any proposed solution.

The next step is therefore to define, in ISO 15288 terms, the Solution Space. As the name implies, we need to set bounds, to limit, albeit loosely for now, the scope of any potential solutions, we need to define what technologies we can include and what constraints we are operating under. Constraints may include but are not limited to, international treaties, government policies, financial limitations, manpower limits, physical dimensions, and schedule constraints, etc.

However, that may be many, many potential solutions within the defined Solution Space that have the capacity to meet the stakeholders' needs. ISO 15288 introduces the term "Solution Classes" to address the highest level options that occur within the Solution Space (e.g. our mine clearing options introduced above, mechanical, electronic, explosive) and whilst these terms may seem somewhat esoteric initially, they are simple and elegant concepts.



The Solution Space bounds the potential solution, it is in effect comprised of a number of constraints on the solution.

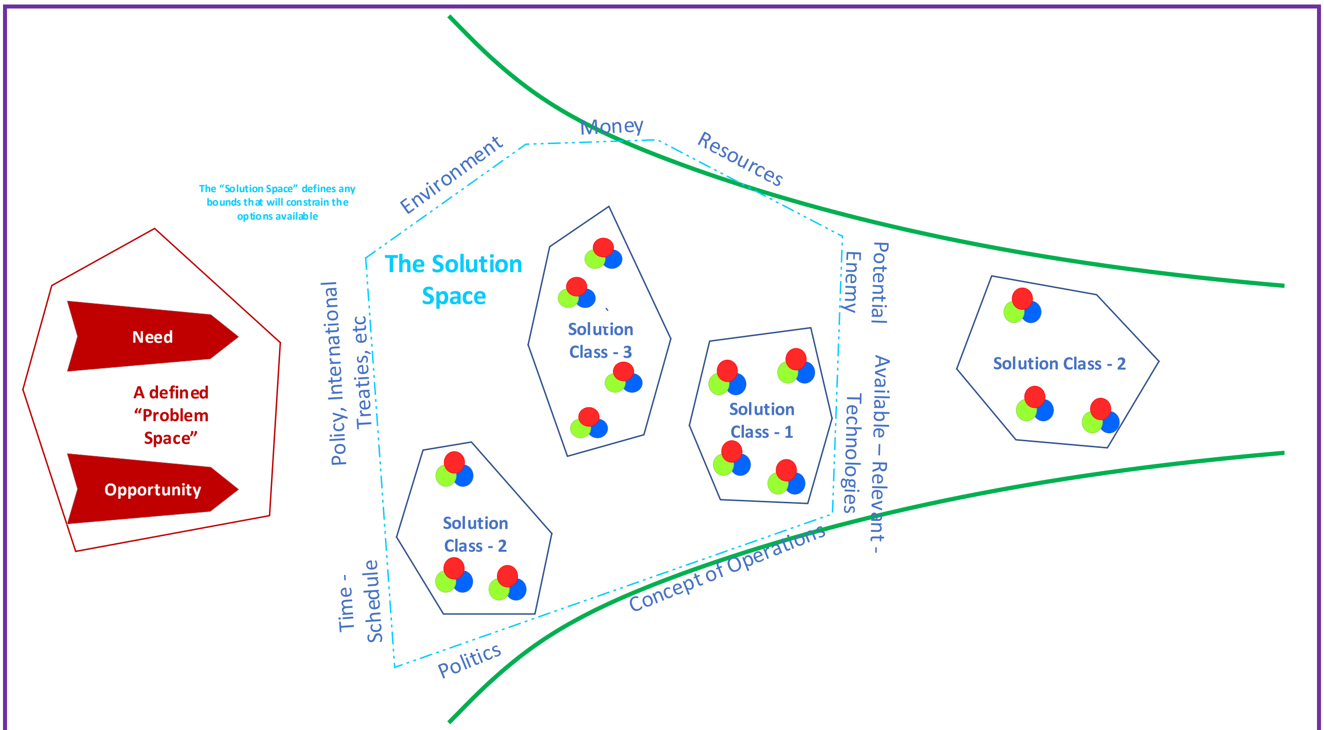
Within the solution space we define one or more Solution Classes; using the examples in this paper:

1. Solution Class 1 = mechanical mine clearing systems
2. Solution Class 2 = electronic mine detection systems
3. Solution Class 3 = explosive shock detonation systems

Given that we are not blessed with infinite time or resources, we can rarely afford to pursue two or more such alternative Solution Classes concurrently, each of which may include many viable alternative solutions (e.g. many varieties of mine plough). Deciding which is the preferred option is the start of a complex iterative - go around the process loop until you achieve the desired outcome (*or kill the process*) and recursive - apply the process at successively lower levels in the system hierarchy, Systems Engineering process.

The examples above utilise very different types of technology, it is not sensible to embark on the follow-on, more detailed processes (*more expensive and more resource dependent*) until we have decided between them. Self evidently (*I hope*) it would not be possible to define a set of technical requirements that embraced both mine ploughs and mine detectors.

Hence, once we have defined the potential solutions at a high level, the Solution Classes, our aim is to fairly rapidly and cost effectively, whittle these options down to something more manageable in readiness for the next phase of development. In order to enable this down selection process each Solution Class has to be defined to a level of granularity that will allow meaningful evaluations to be carried out.



One of the key tasks in the Concept Phase is to narrow down the options in readiness for the following lifecycle phases.

As the options reduce, the options also mature, i.e. both the ‘*design’* and the ‘*requirements’* mature and a greater level of detail has to be captured.

Note*: Once you have selected a specific Support Class, for example a mechanical mine clearing system, you have started the design process.*

If you have defined any performance parameters for that system, e.g. that it must be air portable in a C17, then you have started the requirements definition process.

In the Concept Phase, we need, as a minimum, to define the Solution Class which will be taken forward into the subsequent life cycle phase.

Subsequent Systems Engineering activities will narrow down the actual solution options (*represented here by the three circles*). As the options reduce, the level of granularity to which they are defined **must** increase.

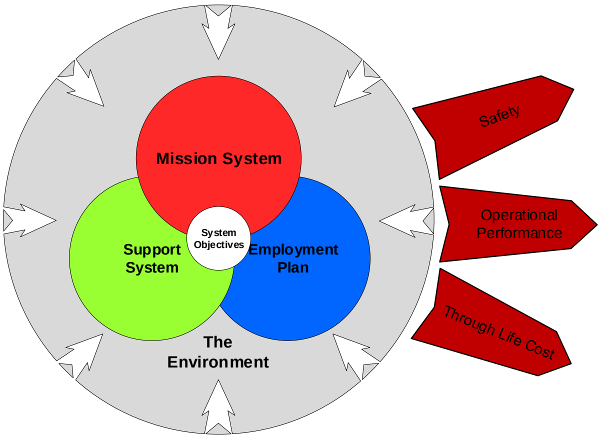
A large part of the selection process involves comparing the system capabilities with the needs as defined by the stakeholders of course, the selected option has to meet the operational need. But in order to meet this operational need the fielded system, the **Mission System**, has to be available, it has therefore to be reliable, maintainable, testable, durable, robust, transportable etc; it has to be supportable.

But whilst we have defaulted to discussing actual equipment in the illustrations above, i.e. alternative Mission Systems, it is critical that we apply the same logic to all elements of the potential Support Solution. Whilst operational effectiveness is dependent on Mission System availability, Mission System availability is not only dependent on the support characteristics of its design, but also on the effectiveness of the associated **Support System**. The Support System has to incorporate sufficient support resources, it requires efficient and effective support processes and support contracts, all of which come at a cost.

Similarly, the behaviour of both the Mission System and the Support System are dependent on the manner and the environment in which they are operated, the **Employment Plan**. The Employment Plan effects those characteristics that are inherent in the system design, for example, the reliability of the system will be determined to a large degree by the operational environment, arising rates will be determined by the operational tempo, etc. Arising rates will also be determined by the nature of (*the capability of*) the Support System, effective training, technical publications and test solutions will lead to lower No Fault Found [NFF] rates, poor solutions will result in high NFF rates, high TLC, poor system availability and increased system vulnerability. It is critical therefore that the associated “Employment Plan” is defined if a meaningful evaluations of the options are to be carried out.

The Solution, at this stage the preferred Solution Class, has to be affordable, in terms of acquisition costs and TLC as well as providing the desired operational capability. These characteristics are determined by the Mission System, the Support System and the Employment Plan - collectively referred to as the “Total System” - and the interactions between them.

It is essential therefore that we address the design of the elements of the Total System concurrently if meaningful evaluations of the options are to be possible.



It is the "Total System" and the interactions between its elements, that determines performance, therefore the Total System has to be defined and analysed during the Concept Phase – albeit at a high level.

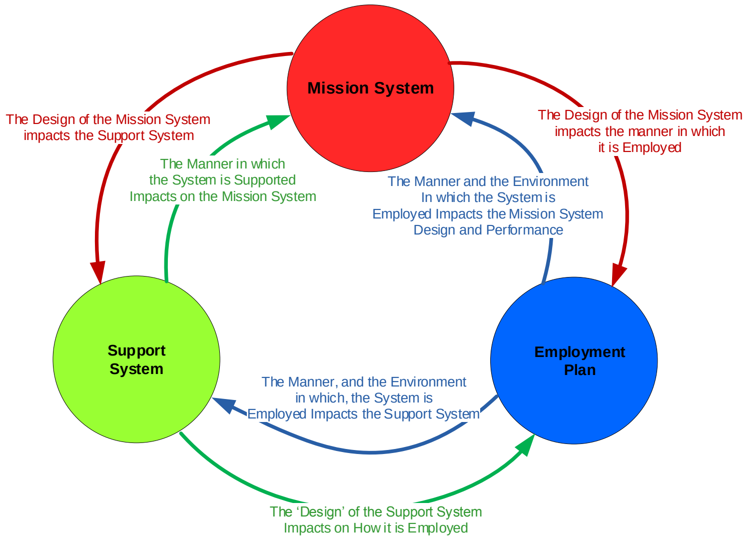
The Solution Space and the Solution Classes (*and ultimately the Solution*) must therefore address all three elements. Definitions of each element need to be developed, they each need to be "Baselined" during the Concept Phase. The support aspects of each of these elements collectively comprise the embryonic Support Solution.

The creation of such definitions, the development, the use and the evolution of Baselines is a topic in its own right. Suffice to say here that they are initially based on extant systems, leavened with an awareness and an understanding of new and evolving technologies, doctrines, methodologies, etc and that they are used to facilitate the down selection, requirements generation and planning processes.

We also need to deploy some mechanism for evaluating these options, these mechanisms may include qualitative and quantitative methods. Quantitative methods are preferred but often bypassed during early life cycle phases. The apparent lack of information on which to base such analysis being the reason for not conducting such processes; it is a common stumbling block. It is stating the blindingly obvious that data on the future systems generally is not available, for the simple reason that those systems often do not yet exist; so where do we start?

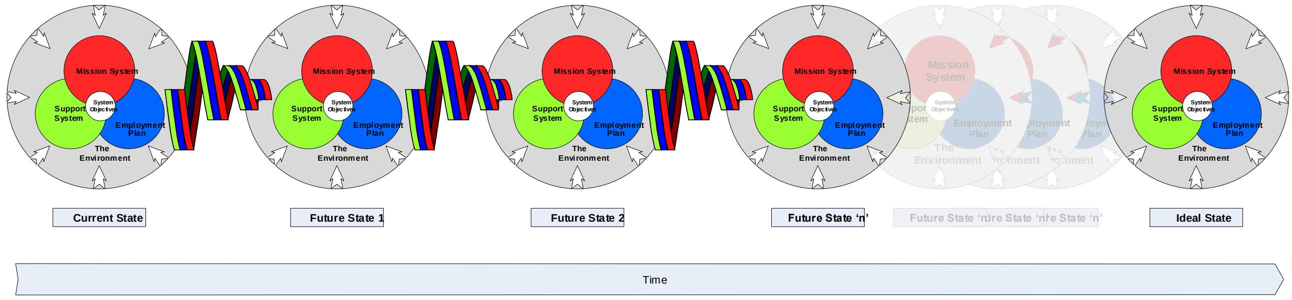
The answer is that such information is derived, in the main, from historical data captured in the form of the system baselines. Few systems are totally new, they are mostly comprised of existing technology, or developments of existing technologies, mixed with a small percentage of something genuinely new. The intelligent use of historical data will therefore provide a sound baseline for our future systems. The concept of a system 'baseline' is very simple, but very powerful, baselines should be created for the Mission System, the Support System and the Employment Plan. Such baselines can then be used to capture information such as operational, manpower, technical or financial constraints, details of stakeholders, Lessons Identified, Risks and Opportunities, Assumptions, System Interfaces, Performance Indicators, etc.

Given that one of the aims of Support Engineering is to deliver and to maintain an optimal Support Solution then the use of a model or models of some form is more or less inevitable. These baselines provide the data and information that is required to populate appropriate performance and TLC models.



The complexity of the Total System, and the interactions between its elements, makes the use of models more or less inevitable, if we are to run an effective Support Engineering programme.

There is a strong argument for making the use of models a key element of any Support Engineering programme, because they help us to understand the often complex relationships between cause (*Total Systems design*) and effect (operational effectiveness and TLC); this is the philosophy behind the concept of Model Based Systems Engineering [MBSE]. There are a great many models and modelling technologies etc available today, ranging from highly capable simulation packages to both simple and very complex Microsoft Excel based tools; various alternatives may be deployed at different points in the programme. A programme analysis and modelling strategy should therefore be developed which considers what models will be used, for what, why and how; the role of the baselines, and their future iterations, should form an integral element of such a strategy which should of course be initiated during the Concept Phase.



The Baselines evolve over time as the Systems Engineering, iterative and recursive, development process is applied.

Baselines also provide a robust basis for requirements generation. Our baselines will inform us as to the performance of extant systems (*in support terms in our case*), operating in accordance with and under the conditions defined in the present Employment Plan, supported in accordance with the extant Support System. That is, we will know what is being achieved today, we will have quantitative performance data, e.g. availability, reliability, maintainability, costs, spares usage metrics, details of the top ten systems driving poor availability, the top ten system driving in cost etc. We will also have qualitative feedback information, derived from discussion with the stakeholders, they will inform us of the positive and the negative aspects of extant systems, i.e. those characteristics that they would like us to preserve and those that would like us to eliminate, these are Lessons Identified [LI's] positive and negative.

All of which we provide us with a foundation for developing future, SMART requirements (Specific, Measurable, Achievable, Relevant, Time bound). We should look to address, via the requirements generation process, any Risks and Opportunities we have defined and any Lessons Identified, either by creating a Technical Requirement or a Statement Of Work [SOW] (*to be addressed in later life cycle phases*).

Managing Support Innovation…

When we are presented with an operational need or a negative "Lesson Identified" which conventional technologies or methods cannot satisfy, then one solution may be to deploy new technology. Ultimately a Concept Phase decision to deploy new technologies may be reflected in the evolving requirements and system design; but the deployment of such technology has to be feasible; technically, financially and in terms of the programme schedule. Hence we need to evaluate extant and emerging technologies that may address support issues; we also need to assess new technologies, which may be incorporated into the solution, and which may introduce support issues.

It is at this point that a project should be considering alternative "*Support* Solution Spaces", for example:

- Alternative manufacturing and repair technologies
  Solutions which may be deployed forward, for example, Additive Manufacturing, Automated machine tools, etc,
- Automated data collection
  The use of smart mobile devices, modern diagnostic tools, Condition Based Monitoring, Sensor RFID's, Data bus technology (e.g. similar to the On Board Diagnostics [OBD2] standard fitted to modern road vehicles).
- Tracking systems
  Smart packaging, embedded RFID, NFC, data loggers, etc.
- Electronic publications technologies
  3D graphics, Augmented Reality [AR], Audio, Video, ePubs, integration with training systems, integration with data collection process, dynamic HTML5 documents, integration with HUMS and BITE, etc.
- Training approaches and technologies
  Virtual Reality [VR], AR, Mixed Reality [MXR], train forward, remote mentoring, etc.
- Updated (user friendly?) Maintenance Management Systems [MMS].
- Intelligent warehouses.
- Condition Sensors
  Sensor RFID, Data Loggers, Virtual Sensors, etc.
- UAVs - Quadcopters
  For stores delivery, for conducting inspections, etc
- Alternative support contracting mechanisms.
- Etc.

This is just a random selection, there are many, many more options, the point is that such options (*as appropriate*) should be evaluated during the Concept Phase, and each element of support should be considered. The conventional approach should not be the default solution.

Each option for introducing new support technology should be subject to evaluation, for example we need to assess:

- The potential benefits that the technology could bring, i.e:
  - The potential cost impact
    In terms of acquisition cost and TLC, but considering also the potential negative impact if the technology fails to live up to expectations.
  - The potential operational impact
    e.g. the improvement in availability if it works, but also if it doesn't work as expected.
- The maturity of the technology
  Much attractive technology is already mature and robust but other leading edge technologies will introduce an associated technological risk. This does not mean that they should be automatically rejected, we are in the Concept Phase after all, but we do have to make a judgement as to how feasible the technology is and whether the level of risk is acceptable or not.
- The potential impact on the programme schedule
  If the technology takes longer to mature than anticipated.

This does require the Support Engineer to gaze into the future somewhat they must be constantly horizon scanning, looking for new opportunities which may improve system support or reduce TLC. They need to consider what technology will be mature, not tomorrow, but at some time in the future when the solution is finally fielded. Just how far into the future they gaze will depend on the nature of the programme.

The results of this activity will impact the planning process of course.

The Support Case…

Given that the aim of such activities is generally to analyse and to make decisions, it is imperative that a robust audit trail is maintained of what decisions were made and of the reasoning that underpinned those decisions. This is particularly important in the world of Support Engineering, due to the probabilistic nature of many of the measures that we deal with. That is, you cannot determine how 'good' many elements of support are by merely examining the support products, this can only be determined via testing or use. However assurance can be provided if a good and laudable process has, demonstrably, been applied. The mechanism for recording such information is the Support Case.

Support Planning…

Such an approach requires planning.

Given the complexity of support and support engineering, given the many variables, constraints, stakeholders etc, that have to be taken into account, it is sensible to approach this process by first defining a Support Engineering programme strategy. This activity should precede the detailed planning process, when we will determine what activities will be undertaken, what standards will be followed, which normal and which innovative processes will be implemented, etc

We should consider the approach that is to be applied, not only during the Concept Phase, but during the remained of the proposed system's life. The ideal approach is to plan the entire life, albeit at a high level, and the next phase in detail. This is rolling wave planning and the result will be a Through Life Management Plan [TLMP]. The effort required to produce such a plan will be minimised is the Total System approach introduced above is implemented. The Employment Plan and Support System baselines, which will evolve during the development programme to define the actual in-service solutions, provide the bulk of the TLMP, i.e. they define how the system will be used and where and how it will be supported. If we add to these the programme plans, i.e. the plans for the Concept Phase, the Systems Level Development *(=UK MOD Assessment Phase*), Full Scale Development *(=UK MOD Demonstration Phase*) and the Manufacturing Phases, we have in effect compiled our TLMP.

The detailed planning process will identify:

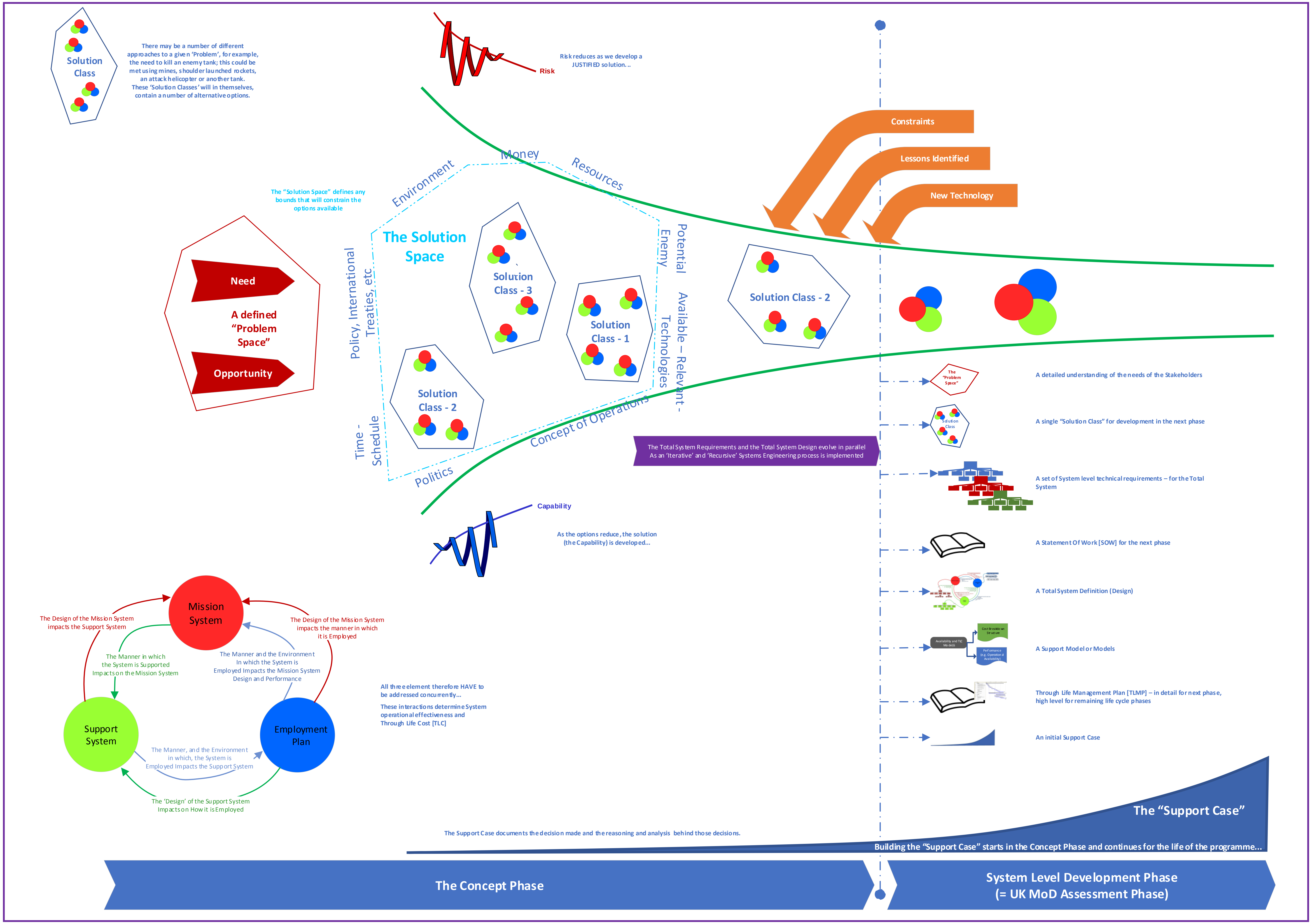
- ❑ The processes that will be applied in each phase
- ❑ The deliverables that will be generated from those processes
    - ○ Support Product deliverables
    - ○ Support Process deliverables (collectively these comprise Support Case)
- ❑ The necessary resources
    - ○ People
    - ○ IT systems
    - ○ Software – databases (for the Baselines) and models for example.
    - ○ Data,
    - ○ Etc
- ❑ A programme schedule
- ❑ Dependencies
- ❑ Responsibilities
- ❑ Programme costs
- ❑ Etc.

The End Game

So what should we be able to deliver at the end of the Concept Phase? We should have:

1. A detailed understanding of the needs of the key stakeholders.
2. A single "Solution Class" for development in the next phase of the Life Cycle (*e.g. this could be a hand held mine detector, in our illustration*).
3. A set of system level Technical Requirements.

4. A Statement of Work for the next phase of the Life Cycle – this may include activities which will be conducted by the client themselves (the basis of an internal Support Engineering Programme Plan) and activities that will be conducted by contractor (*the basis of a set of formal SOW requirements*).
5. A Total System definition which will evolve over the system lifecycle, this initial version is comprised of system 'baselines'. The Total System definition in the Concept Phase is comprised of:
    a. A Mission System Baseline
    b. A Support System Baseline
    c. An Employment Plan Baseline
6. A Support Model, or models addressing support performance (*e.g. availability*) and TLC which can evolve over the system life cycle.
7. A Through Life Management Plan [TLMP], a rolling wave through life plan with detailed planning in place for the next phase of the Life Cycle.
8. An initial Support Case, which will evolve over the system life cycle, but which at present provides an audit trail documenting what decisions were made which led to and which justify (*by defining how and why those decision were made*) the solution presented above.



Solution Class
There may be a number of different approaches to a given 'Problem', for example, the need to kill an enemy tank; this could be met using mines, shoulder launched rockets, an attack helicopter or another tank. These 'Solution Classes' will in themselves, contain a number of alternative options.
Risk
Risk reduces as we develop a JUSTIFIED solution…
Constraints
Lessons Identified
New Technology
The "Solution Space" defines any bounds that will constrain the options available
Environment
Money
Resources
Potential Enemy
Available – Relevant - Technologies
Concept of Operations
Politics
Time - Schedule
Policy, International Treaties, etc
The Solution Space
Need
A defined "Problem Space"
Opportunity
Solution Class - 3
Solution Class - 1
Solution Class - 2
Solution Class - 2
The Total System Requirements and the Total System Design evolve in parallel
As an 'Iterative' and 'Recursive' Systems Engineering process is implemented
Capability
As the options reduce, the solution (the Capability) is developed…
The "Problem Space"
A detailed understanding of the needs of the Stakeholders
Solution Class
A single "Solution Class" for development in the next phase
A set of System level technical requirements – for the Total System
A Statement Of Work [SOW] for the next phase
A Total System Definition (Design)
Availability and TLC Models
Cost Breakdown Structure
Performance (e.g. Operational Availability)
A Support Model or Models
Through Life Management Plan [TLMP] – in detail for next phase, high level for remaining life cycle phases
An initial Support Case
Mission System
Support System
Employment Plan
The Design of the Mission System impacts the Support System
The Design of the Mission System impacts the manner in which it is Employed
The Manner in which the System is Supported Impacts on the Mission System
The Manner and the Environment In which the System is Employed Impacts the Mission System Design and Performance
The Manner, and the Environment in which, the System is Employed Impacts the Support System
The 'Design' of the Support System Impacts on How it is Employed
All three element therefore HAVE to be addressed concurrently…
These interactions determine System operational effectiveness and Through Life Cost [TLC]
The Support Case documents the decision made and the reasoning and analysis behind those decisions.
The "Support Case"
Building the "Support Case" starts in the Concept Phase and continues for the life of the programme…
The Concept Phase
System Level Development Phase
(= UK MoD Assessment Phase)

But…

I am sure that one of the immediate responses to such a proposition will include the cry, “But we can’t afford to do this…”.

The reality however is that these output can be derived in a rational structured manner or in an irrational unstructured manner, but most of them will have to be derived eventually.

The unstructured approach may possibly cost slightly less during the Concept Phase, but I suspect that often more time and monies are expended simply because the approach is unstructured and many processes are merely slipped into later phases when monies will be expended in any event as the programme plays catch-up.

The approach outlined above, will provide a very sound foundation for the System Level Development phase processes (*the Assessment Phase in UK MoD parlance*), with a subsequent saving in time and cost It will also deliver significant benefits in terms of overall programme performance.

In summary, I believe that not doing it will cost more, not less, than doing it. Note also that I am not including any outcome costs here, i.e. I am only addressing programme costs, not any in-service support cost savings.

Another contention will be, despite the arguments that I have made above, that there simply is no data available to support such an approach. This is rarely, if ever, true. We have historical FRACAS, DRACAS, spares usage data, bay records, contract data, servicing records, etc, that we can utilise. We can assess data from allied nations, from suppliers, from commercially available databases, we can talk to maintainers, suppliers and operators. Whilst this may not be in a format that permits immediate use, it is not beyond the wit of most Support Engineers to manipulate such data until it is in a usable form.

Consider also, that once Employment Plans and Support Systems have been baselined, it should be possible to reuse much of the information on other programmes in the same domain, i.e. within the Maritime, Land or Air environments. Once created these baselines can become valuable, reusable, assets. The process will get easier and cheaper on each successive iteration.

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