The Systems Engineering Tool Box

Dr Stuart Burge

"Give us the tools and we will finish the job"

Winston Churchill

Needs Means Analysis (NMA)

What is it and what does it do?

Needs Means Analysis (NMA) is a systems thinking tool aimed at exploring alternative system solutions at different levels in order to help define the boundary of the system of interest. It is based around identifying the "need" that a system satisfies and using this to investigate alternative solutions at levels higher, the same and lower than the system of interest.

Why do it?

At any point in time there is usually a "current" or "preferred" solution to a particular problem. In consequence organizations will develop their operations and infrastructure to support and optimise that solution. This preferred solution is known as the *Meta-Solution*. For example Toyota, Ford, General Motors, Volkswagen *et al* all have the same meta-solution when it comes to automobile – in simple terms two-boxes with wheel at each corner. All of the automotive companies have slowly evolved in to an industry aimed at optimising this meta-solution.

Systems Thinking encourages us to "step back" from the solution to consider the underlying problem or purpose. In the case of an automobile, the purpose is to

"transport passengers and their baggage from one point to another"

This is also the purpose of a civil aircraft, passenger train and bicycle! In other words for a given purpose there are alternative meta-solutions. The idea of a pre-eminent meta-solution has also been discussed by Pugh (1991) who introduced the idea of *dynamic* and *static design concepts.* Pugh argues that most systems are conceptually static – the basic design concept has not changed for decades if not centuries. Indeed, the automobile is a classic example whose basic concept (the two boxes and a wheel at each corner) has not change now for over 100 years. Despite this seemingly slow progress, Pugh argues that these static concept design concepts have changed out of all recognition at the sub-system level. Lifting the bonnet or hood on a modern automobile would confound and surprise Henry Ford or any of his contemporaries, with the advent of electronic fuel injection (EFI), Engine Management Systems (EMS), Anti-lock Braking Systems (ABS), Climate Control Systems (CCS) to name but few of the sub-systems found in a modern car. Similar statements can be said about the banking system, the education system etc. As overall concepts the current versions have been with us for decades and centuries, change has taken place at the sub-system level.

It is, indeed, the shear perseverance of a meta-solution that has allowed designers to "jump to" or assume the meta-solution and therefore more rapidly into detail design. It supports the reductionist approach and "solutioneering". Such organizations, however, are treading on increasingly thin ice because customers are fickle creatures! Every "system of interest" is a sub-system of a higher-level system. Examining the system of interest from the viewpoint of the higher-level system to which it belongs encourages the consideration what it does and the need it satisfies. It must be remembered customers do not buy systems they buy the capability to satisfy a need. For example, Airbus and Boeing do not buy gas turbines they buy power systems because they need thrust and power. If an organization was to present them with an alternative to the gas turbine that was a "better" solution to providing power they would buy it! However, from Rolls-Royce's or GE's viewpoint their solution to providing power is the gas turbine – it is their meta-solution. Their whole infrastructure is geared up to designing and building gas turbines. It is what they know.

A shift of meta-solution can literally destroy a company. The classic example of recent years is that presented by Edwards Deming (1986) of the automobile carburettor. Until the late 1970's the carburettor was the dominant solution to provide an air-fuel mixture. Fuel injection was rare because of its cost and poor reliability. The various carburettor manufactures considered their business safe and concentrated their research effort into developing a better carburettor rather than generic problem of providing the internal combustion engine with an air-fuel mixture. The advent of Electronic Fuel Injection that providing a reliable, low cost, high quality method took the industry by storm. Within a very short space of time the carburettor manufactures one by one went out business. Today, all of the famous names in carburetion have gone excepting those for motorcycles and lawn mowers.

It makes sense therefore, when considering the design of a new system, or sub-system, even down to components, to review the meta-solution to consider alternatives and narrow or broaden the scope of work. Need Means Analysis is a simple tool that allows this exploration of alternative solution to be undertaken quickly thereby providing the information to clarify the scope.

Where and when to use it?

Need Means Analysis is scalable and universal (it can be applied to any type or size of system) and most usefully employed in the early stages of determining system requirements. Typically, it is used following some requirement elicitation and capture, although its outcome may result in a change of system scope leading to further requirements gathering.

Who does it?

Need Means Analysis can be performed by an individual or team. If the system of interest is a component then it is most likely applied by an individual. For larger system it is best performed by a team to draw upon the experience and expertise in that team. It is important to emphasise that the quality of the outcome is dependent upon the experience of team or individual.

How to do it?

The process for conducting a Needs Means Analysis comprises five steps:

Step 1: Define the scope of the current system of interest. That is, the current meta-solution

Step 2: Identify the Operational Requirements[1] of the system of interest

Step 3: Using the operational requirements derive the NEED that the current system of interest satisfies. It is related to, but is likely not to be the same as, the Operational Requirement.

Step 4: Use "the box of nine", shown in figure 1, to identify new solutions to the need at different levels. The box of nine provides the minimum number of ideas sought to make the analysis meaningful. It should not restrict the inclusion of more than 3 ideas per level.

The three levels are:

- Higher level new system level. This can be determined by consideration of the question: "can the need be met by a new system that does not require the ownership of the current system of interest?"

[1] **Operational Requirements** define the major purpose of a system (i.e. what it fundamentally does; its capability) together with those key overarching constraints (that define the context of the system). See Holistic Requirements Model tool.

- Same level new architecture. This can be determined by consideration of the question “are there alternative architectures for the current system of interest?” This can often change the overall purpose to include new functionality and a modified purpose.
- Lower level new sub-system. This can be determined consideration of the question: “can the current system of interest be improved by changing a sub-system?”

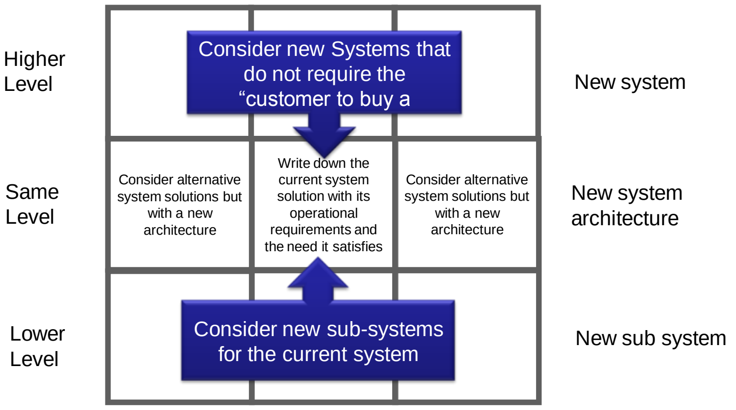

Figure 1: Need Means Analysis “box of nine”

Step 5: Review the Need Means Analysis to agree the approach

- Innovation through utilising the existing meta-solution but making changes at the sub-system level. Innovation involves improvements at the sub-system level. This is often sufficient to keep a product in the market place provided there is not a shift in meta-solution. Overall this level of improvement is of the lowest risk. A classic example of innovation at the sub-system level is the Dyson Vacuum Cleaner. Fundamentally this very successful product is a consequence of a cyclone technology, which is a sub-system improvement.
- Radical change through new system architecture for meta-solution. New architectures often provide a step-change in performance of a system, but this is balanced by the general reticence of the customer/user to “try something different”. If it is accepted by the customer/user it can provide a significant commercial advantage. A good example is the Apple ipad – fundamentally a computer but one that has completely different architecture to other computers. This level of improvement is very risky – if the new architecture is not accepted by the customer/user then the system will fail.

- Revolutionary change through brand new meta-solution. This is the most risky improvement but one, that if successful, will reap the biggest rewards. A classic example here is Bosch's electronic fuel injection system introduced in 1967 and perfected in 1982 saw the demise of the carburetor.

In reviewing the "box of nine" chart the choices relate very much to risk

Illustrative Examples

Need Means Analysis is best explained by example. The first is for a conventional automatic washing machine. The box of nine is shown in figure 2.

Cleaning Service	Disposable Clothes/ Items	Holographic Clothing
Twin Tub	Washing Machine OR: Wash Items Need: Hygiene	Combined Dishwasher
Ultrasonic Cleaning	Fuzzy Logic Control	Auto Powder Dispensing

Figure 2: Need Means Analysis for an Automatic Washing Machine

In this example the central box contains the current system of interest: an automatic washing machine. Its operational requirement is to wash items (automatically, economically and without damage). Its need, however, is different. We own an automatic washing machine to clean out clothing items but why? The need is basic hygiene. To remain hygienic we regularly clean are clothing items. Understanding the need correctly is critical to performing a Need Means Analysis since to explore alternative in the higher level requires answers to the question "can hygienic clothing be provided without the need for owning an automatic washing machine?" There are many answers all of which from the viewpoint of the system of interest are revolutionary. A cleaning service is one such route. This may not appear "revolutionary" but from the viewpoint of a washing machine manufacturer it is! Other options include disposable clothing that is thrown away after one use, or even holographic clothing projected onto the user's body! It may be possible to generate further ideas at any level. For instance, at the higher system level, a further option is dirt resistant fabrics. These further alternatives can be appended to the "box of nine".

The middle level of the "box of nine" is concerned with answering the question "can hygienic clothing be provided with a washing machine with a new architecture?" This means the user will own a washing machine but one that may look different to the conventional white box. This may be combined washing machine and dishwasher, a "photocopier" approach where the clothes are inserted one at a time, - i.e. still a washing machine but one that has a different structure and organization.

The third level is concerned with exploring different sub-systems. The improvement takes place on the sub-system level so that outwardly the user will see the same exterior. There are often many choices here and it may not be necessary to capture all of them at this point (this is because they are likely to be captured and refined later)

Having completed the "box of nine" the matrix should be reviewed as to where the organization wishes to focus:

- Move to the higher level and consider revolutionary change
- Change the architecture – radical change
- Innovate at the sub-system level – innovative change

These decisions are not trivial and involve differing level of risk.

A second example, shown in figure 3, is for a manual lawn mower.

Lawn cutting Service	Artificial turf	Genetically modified slow growing grass
Autonomous Lawn Mower	Manual Lawn Mower OP: Cut Grass Need: Attractive Lawn	Sit-on Mower
Laser blade cutting	Single ball turning	Mulch cuttings

Figure 3: A Need Means Analysis for a Manual Lawn Mower

Once again the Operational Requirement (cut grass) is not the same as the need (attractive lawn) and therefore it is relatively easy to determine new meta-solutions that do not require the user to own a lawn mower. It is interesting to note that in the UK all the three higher level meta solutions are now available as serious alternatives to owning a lawn mower.

The middle layer of the box-of-nine considers new architectures of which an autonomous or robotic lawn mower is one option while the ride-on mower represents another. Interestingly, an alternative inclusion on this level would be a goat or a sheep!

The lower level presents changes at the sub-system level. Again externally the mower may remain the same but change occurs inside. An interesting option here is the laser blade cutting since this could also reside at the new architecture level. I might be possible to a have single rotating laser placed in the centre of the lawn – a simple 360^0 rotation would result in perfectly cut lawn!

Need means analysis can be applied at any level right down to individual components. Figure 4 shows a Need Means Analysis for a rivet!

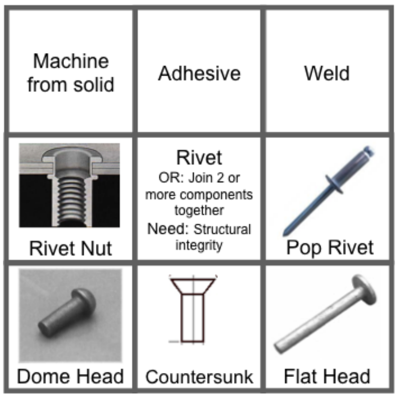

Figure 4: Need Means Analysis for a Rivet

Need Means Analysis can also be used for any type of system. Figure 5 shows a Needs Means Analysis for a support system.

User Repair	Postal Replacement	Redundant System
Out-source "Man in a Van"	"Man in a Van" to repair system at users home OR: Fix System Need: Working System	Prognostic based system
Computer – internet based technical publications	Electronic/ software based diagnostics	Internet based booking service

Figure 5: a Need Means Analysis for a Support System

Once again the centre box contains the system of interest and its current meta-solution of a "man in a van" responding to failures in the field through a central call centre. The Operational Requirement of such a system is to "fix" the mower but the need expressed by the customer is a working mower. Hence the higher-level question is can I have a working mower with out the need for a man in the van?

What Goes Wrong: The limitations of Need Means Analysis

Incorrect and/or incomplete Need. It is important to think through what the need is that a system of interest provides. It can often be established by asking "why" in response to the purpose expressed in the Operational Requirements. For example the purpose expressed in the Operational Requirement for the lawn mower is to "cut grass". In order to determine the need the question "why do users cut grass?" will lead to the need of an attractive lawn.

Placing solutions at the wrong level. This is a common problem but one that often does not greatly matter. However, a few simple steps can avoid this. The highest level (new system meta solution) fundamentally provides a new way of satisfying the need that does not require the user to own the current system of interest. An example of misplacement is the inclusion of "sheep" or "goat" as a new system for the lawn mower Need Means Analysis. Sheep or goat would be better placed as a new architecture – because they are still lawn mowers!

Wrong expertise and insufficient experience in teams. Like a great many Systems Engineering tools, Need Means Analysis is really only a vehicle to help extract the knowledge and experience from the team. The wrong team can still follow the process and arrive at a result – but the result may not fully explore the options available and therefore there is a risk of insufficient information in deciding on the meta-solution.

Success Criteria

The following list represents a set of criteria that have been found to be useful when using Need Means Analysis.

- Team size
  - For Systems between 4 and 8
  - For Sub Systems between 2 – 5
  - For Components 1
- Team constitution has expertise and experience in the system of interest but can (and perhaps should) include members with limited experience and expertise
- Use an experience independent facilitator
- Plan for one hour's effort.
- Define clearly what we are trying to do

References

Pugh, S. (1991). Total Design: Integrated Methods for Successful Product Engineering. Addison-Wesley. ISBN 0201416395

Deming, W. Edwards (1986). *Out of the Crisis*. MIT Press. ISBN 0-911379-01-0