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Philosophy of Master-Planned Test & Evaluation

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ABSTRACT

Test and evaluation, in some form or the other, has always been a major component of the development and operation programmes relating to major defence systems. The traditional process is based on a largely unaccountable and non-inheritable process in which professionalism is thought to be sufficient to ensure that the programmes achieve performance targets. After years of evolution, the US Congress legislated around 1983, for the 'master-planned test and evaluation' process to be used under compulsion of law. This much improved test and evaluation process is outlined using a major defence procurement failure—that of the seventeenth century warship the 'Vasa'—as a case study to highlight the main features of the test and evaluation master-planned (TEMP) method.

1. INTRODUCTION

In the development and operation of large technical systems, extensive use is always made of testing and other means to obtain data on the basis of which system performance, delivery and cost can be assessed. In recent times, there has been renewed interest in development and application of more reliable methodologies that use a specific philosophy for conducting test and evaluation (T&E) to improve the system development and operation process. This is best described as the master-planned approach to T&E and is intended to be a tutorial statement only.

An interesting way to appreciate the problems that can arise is to first run through one of the world's defence acquisition disasters—that of the ill-fated 'Vasa', a 64-cannon warship of the seventeenth century. Whilst, this instance was a Swedish acquisition failure, this example does not reflect that Sweden alone had these difficulties—the 'Mary Rose', an English galleon of the same period had a similar tale of operational unsuitability. Vasa is chosen, as it serves as a good case study. A brief account is given regarding the acquisition record of the Vasa to illustrate features of the process that are relevant even today. This will build up the reasons why the master-planned approach offers greater control over the systems engineering process and how it drives towards the maximum that all systems developers and users chase today: 'more performance for less cost and in less time'.

2. WARSHIP 'VASA' - CASE STUDY OF A SIGNIFICANT ACQUISITION FAILURE

After many years of sea battles, Sweden had insufficient number of warships and needed to commission more. Strength at sea was important to both Sweden and its opponent nation, Poland.

In 1625, King Gustavus II Adolphus of Sweden signed a contract with the Swedish shipbuilder Henrik Hybertsson to build what the King wanted—the best warship till then. It was to be called the Vasa. When asked what size of ship

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was needed, the King replied that he needs a ship of usual size but with more cannons than that of the King of Poland's best ship. It had to be more intimidating than that of the best Polish ship. Over 1000 of the nation's protected oak trees were axed for the task. After several months, the keel was laid. The King visited the shipyard. He then asked the ship to be made longer, as it had to be bigger than that of the King of Poland. While the hull was ready to launch, the ship's builder, Henrik Hybertsson, died in 1627. Hein Jakobsen took over at a stage when little could be done to alter the main characteristics of the ship.

After launching, as the superstructure was being built, the King asked for the stern decks to be higher than those of the King of Poland's ship and for good measure to increase the number of main large cannons to be 64. Each cannon weighed approximately 1 tonne. The ship's displacement was 1210 tonne. The hull was 47.5 m long and the stern height out of water would have been 19.3 m. Testing for stability was done by getting 30 men to run back and forth across the ship whilst it was moored at the dock. After just three runs, they had to stop, for the roll amplitude was already a cause for concern. Normally, at least 20 such excitations were needed to get to the same degree of roll. Present at the test was Admiral Klas Fleming, the most influential person in the Swedish Navy. The only comment recorded by him was 'if only the King were home'. No action was taken to rethink about the design, but it was clearly top heavy.

The ship had to be commissioned in time as it was needed badly and the King was expecting it. So, on 10 August 1628, the Vasa began her maiden sea voyage from below the Royal Castle in Stockholm harbour. Ballast was as much as it could bear and the ship was low in the water. On board for the sail out of the harbour were the 100 plus crew and their families. The gun ports were raised for a full round of cannon fire and more sail was raised as the ship passed out of the harbour. A gust of wind caused it to heel in a disconcerting manner, but the crew recovered it by that time. As the ship rounded to leave the harbour entrance, it heeled over even more. The lower cannon port holes had not been closed. The ship filled rapidly and sank with a heavy loss of life. The Vasa had been in service for just 1.3 km.

The King was overseas at that time and so he heard the news two weeks later. The Captain was imprisoned to await the official enquiry which began within 12 hours of the sinking of the ship. He defended his crew as not being intoxicated, that the ship was ballasted as much as possible, that the guns had been secured and only as many men as the King had contracted for, were on board, but many people could see that it was not stable with its increased number of guns, its old hull shape, high stern, high masts and high sail area. It is important to realise that all such warships of that time were usually close to being unstable. No drawings were used to build them. No calculations were possible at that time. Ship design was done by 'feel' based on experience and designs were handed down as tables of dimension recorded in the 'ship's reckoning'. The Vasa design had gone over the edge—it was too innovative. It was concluded that the ship was just badly proportioned.

The official enquiry could not blame the ship builder, for he had died. The King had formally accepted the basic design and the major changes in it and the Admiral Fleming was a close friend of the King. The inquiry was concluded with no blame to anyone. No one was held responsible.

To end this account, the ship had cost around half-of-the-national gross product to build (The Vasa has since been raised and is now preserved in the Vasa Museum, Stockholm. This case history has been extracted from the accounts held by the museum). This case history brings out weaknesses of their acquisition process and shows how master-planned T&E helps to overcome many of the reasons that culminate in acquisition failure. Readers familiar with modern large system acquisition programmes will easily relate their own experiences with many of the facets of this type of case study.

3. ELEMENTS OF MASTER-PLANNED TEST & EVALUATION

To begin with, the criteria required for a successful programme should be that

- It comes into service in time,
- It is within cost estimates agreed beforehand, and
- Most importantly, it performs as expected.

The Vasa programme may have met the first two criteria, but it certainly failed at the last. It might surprise some readers to learn that many defence and large civilian programmes of all nations, will fail to meet all three at one time. Large systems procurement programmes usually give great attention to day-to-day management functions with respect to the on-time aspect and to the financial control cost aspect, but fail to properly manage the performance aspect.

In view of a very large number of acquisition failures in the early seventees, the US Congress realised the need to work towards a much improved T&E process that concentrated also on the technical performance aspect. They devised the elements of the master-planned T&E process that came into law for defence and other major systems acquisition programmes in 1985, such as civil aviation. Reynolds[1] has reviewed this history. By this time, only the US DoD appears to have master-planned T&E fully in place as a legally required process. Australia is gradually accepting its principles[2]. The International Test and Evaluation Association (ITEA) has documents which provide a more detailed basis for this US movement. The record of the meetings that developed the civilian offering of the first postgraduate award at Georgia Tech. are available[3]

This process is called master-planned T&E. The key feature of the US methodology is the existence of a T&E master-plan (TEMP). This new process is markedly different from the various activities that take place according to a more traditional methodology for ensuring that programmes are staying on track. The traditional methodology that was used by the Vasa contractor is based on the use of programme leader's experience and intuition to drive the process with T&E used when they see the need to perform such functions. This can be a much flawed process that is summed up by the usual statement made in its defence: 'we know, we know what to do, and when to do it—it is a matter of having developed sufficient professionalism. This is a skill that cannot be defined but comes from years of experience and exposure'. In this 'traditional' method of T&E, there is insufficient visibility or traceable records. It often fails to control technical performance risks, because it lacks (i) means to pass over control as staff change, (ii) means to know that one is evaluating to the proper and high level requirements, (iii) records needed to trace back flaws that emerge, (iv) ability to be taught efficiently, (v) methodology that allows advancement by scholarly research, (vi) a scientific underpinning that reduces human and personal issues, and (vii) means to allow time and cost managers a sound basis to make sound decisions in their areas.

The Vasa example is now used to illustrate the features that would have greatly reduced the technical risk control. The death of the first ship architect, Henrik Hybertsson, left his successor in the situation where he would have had great trust (and faith) in the design, for it had come from a great master. Ability to judge the soundness of the project was greatly diminished. There were no records of use to refer to, no specifications that truly pinned down the performance parameters that could be evaluated at that point. Today, they still arise in many programmes, but they need not, as master-planned T&E has the means to go a long way to avoiding the pitfalls.

4 COST OF MASTER-PLANNED TEST & EVALUATION

The cost of application of this form of T&E is often raised as yet another overhead that can be done away with. The programme falls behind schedule, the tests can be truncated to make up time and save costs. They may also be left out due to lack of foresight in planning ahead to ensure that the test resources are available when needed. This issue is also important, for it may take time and considerable budget to build the special test facilities needed. New programmes, both defence and civilian, are usually innovative to the degree that there is no real past example to reuse as it was. The Collins Class Submarine Programme of Australia needed a special underwater test range to be designed and built whilst the submarines were also under development. It had to be a better test range than those existing before it, because the submarine design was aimed to be quieter than the previous models.

When costing the price of adequate T&E, the main cost to focus on is really the cost of not getting the required performance, in time, and within budget. The Vasa may well have provided many jobs for the national economy, but at the end 1000 oak trees and some 100 tonne of castings, etc. ended up as completely written off assets without any service having been achieved. Some readers might argue that Vasa case was an extreme one, for programmes never fail to that extent. Sadly, many still do today: they tend not to be spoken about, as the embarrassment is often too much to accept. In the Vasa case, the nil finding must surely have been due to the closeness of the various relationships to the King. An open and recorded T&E process, based on good science, makes it just so much harder to cover up the blame, but it also greatly reduces the risk of such failure.

Having said this, how much cost is enough? This is a question that is not well researched — or if it has, it has not been openly published, for until the formation of the Australian Centre for Test and Evaluation (ACTE) as a research group in a civilian university. There were scanty open scholarly debates on the issues involved. Perhaps the answer to how much to spend is related more to how much 'insurance' should be taken out. High insurance 'premiums' can certainly be expected, as likely losses can be massive. As a suggestion, a good target to shoot for must be 5-10 per cent of the whole life estimated cost that will be sunk into the programme. On top of this is the national security issue: how much is that worth to assist ensuring that the capability seen to be needed is truly there when needed. Without a sound T&E process, it will not be known how well the national defence system will function until the fateful real life test arises.

5 QUALITY PROGRAMMES NOT ENOUGH

It is not widely appreciated that the quality programmes that have been standardised so much and put into place in organisations in recent decades are actually about ensuring the performance of people and their working support environment up to various levels of 'best practice'. The same applies to the somewhat similar capability maturity models (CMMOs) used in the software industries. These all have built-in direction to ensure that the team is heading down the right path to finally deliver a system that provides the required capabilities. If there are wrong requirements or if their specifications are not correct within the whole of the programme, all of the best human intentions and professionalism will not satisfy the capability needed. The craftsmen who built the Vasa ship did quality work following honoured traditions that passed on how to do it well, but they ended up making only a tourist attraction of great wonder, not a successful battleship.

As well as for the quality programmes, the acquisition process must have another life-long mechanism in place: the best appears to be the master-planned T&E process. It is opined that within short time, the master-planned T&E process will become internationally accepted and there will be international standards for it. The difficulty that holds this up is that there is only one country, the US, that has fully embraced the paradigm and even there it is not accepted at the full breadth of general systems engineering practice. Furthermore, because the nature of large systems acquisition and the systems engineering processes are fast changing to suit better ways to produce large

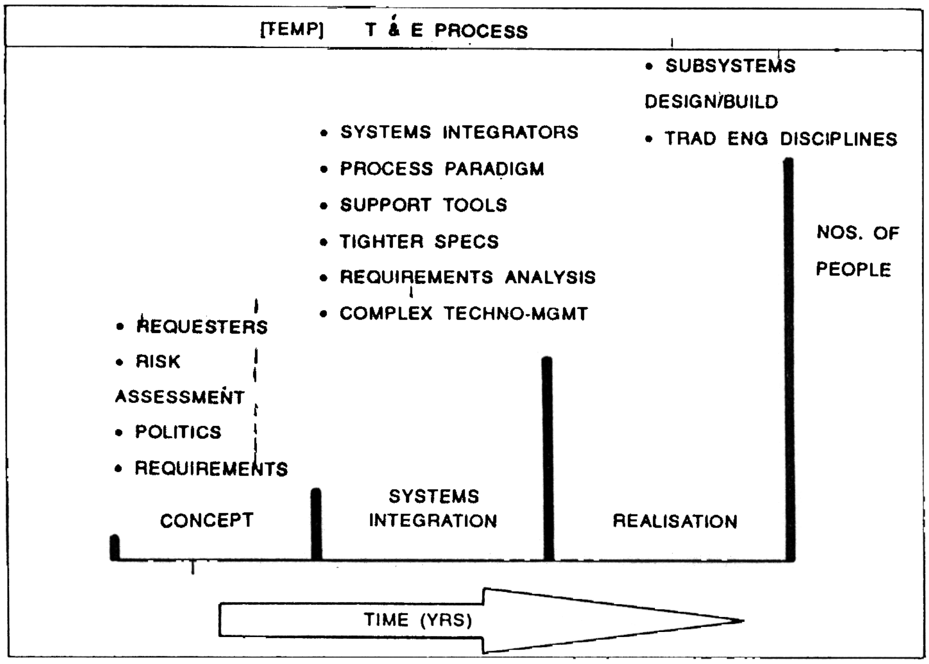

Figure Simplified acquisition process broken into three key stages

systems, it is difficult to see if the basics of master-planned T&E will become general enough for international acceptance.

A battle of two paradigms is emerging between formalising and internationalising the process or keeping it within the company. This has a past parallel with electronic companies that tried to hold on to proprietary operating systems—they eventually gave way to open systems interconnect (OSI) with the result that the whole industry became far more buoyant and progressive.

6. UNIFIED PERSPECTIVE ON SYSTEM PERFORMANCE

Every programme includes considerable testing and evaluation exercises. But too often it is done within the framework of only a relatively limited portion of the whole and that is why systems often fail to meet the needs of cost, time and performance. The test targets need to be well-defined as a part of the whole of the life system. The application of master-planned T&E goes further, as it is a 'whole of process' control mechanism that brings about coordination of needs and does not let the work proceed until performance is assured. The T&E process starts right at the beginning of the acquisition process and runs right up to the very end.

The process must be based on the application of tried and tested principles of the 'scientific method', i.e., to decide a need, set up a way to achieve it and then exercise the solution adequately before declaring it to be sound. The scientific process also brings to programme control the means to significantly reduce human systems issues due to the recorded requirements and agreed upon targets. Such issues that come under better control include overly personal control of activities, semantic differences in interpretation, either wilfully or otherwise, and injection of political influences. Well-expressed and recorded test parameters and statements on how they are to be interpreted, plus justifications, are able to better pin down issues making it harder for subjective thinking to perturb the process.

For our purpose here, Fig. 1 shows a simplistic view of the acquisition process—from declaration of need to the point of acceptance into service—of a major system that can be regarded as having three main steps. Due to the limited space, this account does not explore the use of T&E in operational stages—the same principles are applicable there and are well-established in practice. This paper also does not seek to develop the details of the various T&E variations that must arise with the different forms of systems process now required to be used. The reader is directed to Dvorak[2] for an expose of the issues.

To bring out more of the necessary key characteristics, the Vasa programme can now be switched.

At the beginning of a programme, that is just entering the concept phase in Fig. 1, the capability needed is developed by processes that are usually less than the scientifically based ones. This is justified, as the key capabilities needed are very much set by personal experience of leaders using their intuition. The Vasa was to have more guns and be higher and longer than the best then available ships so as to be more intimidating. Such top level key decisions are usually surprisingly simple to reach, but are very difficult to justify and test in scientifically-based terms. Politics and social needs will enter the picture here, for the capability requirement sets up the base to develop the budgetary cost. An authority should approve the needs statement, allocate the budgets and monitor the progress. Today, some research is openly available to see if a better process can be developed for establishing these early parameters. A recent relevant account is that of Sproles[4].

Usually, there do exist processes which try to verify that the expressed need is sound, but that is not easily done compared with the development of forward estimates of monetary and time-budgeting which are much more real entities to deal with at this early stage than specific requirements of performance. The next step, the integration stage, is that wherein details of the design are progressively developed to yield the capability needed or thought to be needed. This is done by breaking down the capability statement into smaller parts by various methods of reticulation process. Things that can go wrong here, and do so far too often, are cited below:

- The needs statements may already be wrong, because they have been overtaken by other events or were never developed with enough rigour. (Recall here that King Gustavus demanded a longer ship after the keel was laid)
- Politics can enter due to the very large expenditures that develop as the programme grows over time. (They had to complete the Vasa by a certain time, regardless)
- The needs statements are handed over to other people who add their own flavour of bias and influences. (In the Vasa, it was particularly bad, as there was little documentation to refer to)
- The various groups working on design may lack enough communication with other groups and begin to make their own interpretation of the statements given to them
- The capability statement starts to dictate design too early by excessive specifications. This tends to be a modern problem, as more effort is devoted to try to ensure that the customer and the contractor understand the need well enough to avoid extensive cost overruns and possibly expensive litigation.

The time to fix such problems as these is right here; serious design errors left until the end may literally 'sink the ship', as happened with the Vasa. The master-planned T&E concept was devised to ensure that a programme will reach the required performance—and it addresses this aspect in all programme stages, for it is well recognised that flaws in thinking and unsound practices that are exposed and can be easily changed at the early stages. Leaving defects in the beginning can have disastrous results much later. The Vasa was an advanced design, but it went too far; but well before it took its fateful journey it was known to be faulted from the results of the stability test. The programme should have been stopped and reconsidered at that point.

Master-planned T&E indicates that a programme proceeds only if pre-decided performance expectations are demonstrated with definitive tests and evaluations. The Vasa programme, if it had master-planned T&E would have had a document that at least specified the test procedure and the threshold values to be reached at the various stages of build. In that case, it was well accepted that the 30 seamen could run back and forth some 20 times before it should reach alarming roll amplitudes.

At this stage, it might be argued that such testing is always part of a programme and that testing is carried out by contractors in all sub-stages—indeed that is done. The difference in Master-planned T&E is that the whole set of tests are integrated to ensure that they map back to the common top level capability needs and there is a good level of visibility in the plan. An example of poor definition is found in another dramatic Naval acquisition failure; this time it is British. The Royal Navy decided to install big guns with 32 km firing ranges on battleships in the early 1900's. Somehow it was overlooked that the first generation design was defective. The barrels dipped in the water even in mild sea states when the gun was needed for firing. Perhaps, a look ahead to see how the design might perform in the required circumstances could have pointed this fact. They should have seen this with a simple model in a wave tank or perhaps even by using engineering drawings. The Vasa was built in a period when modelling, drawings and computer simulation were not available, but a simple physical model possibly would have shown the defect well ahead of laying the keel.

It is important to recognise that master-planned T&E is carried out with a total whole of life viewpoint. Today, this also means taking the T&E right through to operation and even scrapping requirements as a whole of life process component. So, what can be done to reduce the technical risk?

The master-planned T&E process requires that T&E experts are part of the early deliberations and that those who are to design and make the system also make their inputs. The King would have been well advised to get serious advice on how far he could push the designs and what technical risk he was about to embark upon with his insistence on 'bigger, more guns and higher' capability statement.

The test and evaluation staff are part of all deliberations in that they assist in developing the criteria that define the testable parameters at various stages. In the US, these staff are employed by the DoD, not the contractors. Here arises a fundamental dilemma—how to keep the T&E staff from being too involved with the designer's thinking. On one hand they need to be familiar with major design discussions; yet on the other hand they must not be influenced by those interactions. Thus, the T&E team is a part of design development. Their role is quite different from that of the contracted 'Independent Valuation and Validation' (IV&V) activities that are aimed to accept performance already given to them in the TEMP and other top level documents. So, how does the T&E team operate to control technical risk?

At the end of the concept stage, the King of Sweden, if he had had a master-planned T&E process in place, would have been asked many questions about his capability statement. What was needed was a much tighter statement, in writing, of his want, for that could be translated by his naval and ships' architects into the key measures of effectiveness (MOEs), which, in turn, break down eventually into technical performance parameters that could later be measured with clarity. (Note that the terminology varies widely for systems engineering process parameters and many words are used synonymously!) Without a clearly stated and accepted statement of the need programmes start off without the necessary guidance are needed to control technical risk.

7. TEST & EVALUATION MASTER PLAN DOCUMENT

By now the reader is well aware of the philosophy of master-planned T&E. A process is now needed to ensure that the principles of accountability, traceability and scientifically-based decision-making are maintained. The TEMP document is the physical mechanism that ensures that these principles are upheld. It distils the 'contract' set up between the various participants in the programme—from beginning to end. In the US systems, TEMP is the top level T&E planning document. The TEMP's document are prepared for various periods of the whole of life cycle—for development, operation and more. They are surprisingly small documents containing 20-50 pages only. They state the key test parameters, their threshold values to be met and the test methods and resources needed at the agreed 'show stopper' steps of the programme.

Preparation of TEMP documents is not a trivial exercise but demands that all stages of the programme are well considered to realise the information needed. The Vasa would not have been started under the TEMP control mechanism until a satisfactory requirement statement would have been confirmed by the King. The hull would not have been allowed to progress beyond the stability test after it had failed to reach the roll stability features established as needed. Today, there are more significant programme characteristics to cover in TEMP than in the days of the Vasa. Prototype using computer models and simulations, software maturity, hardware-in-loop stages and physical modelling all need to be allowed for; each must have its relevant tests and evaluations described in TEMP. Another system development and operational characteristic to be reckoned with today is the time-changing nature of technology of the manufacturing processes and the final application of the system. The TEMP has to allow for change and to have flexibility built in for this.

8. INFORMATION SOURCES ON TEST & EVALUATION

Master-planned T&E is, therefore, a relatively new practice. It was not developed in the university environment, but by the US defence and the defence contractor personnel working under contract. The written materials on this are, therefore, not generally available in the open literature. Nor have the paradigm and process been condensed into teaching materials published by commercial publishers. With the advent of civilian university groups, such as ACTE, this issue is now being addressed. As developments in the T&E process in the US and Australia are unclassified work and often in the public domain by law, places to look in this age of internet for information on T&E are from the home pages of ACTE, Georgia Tech.'s T&E Research and Education Centre (TEREC), the Pentagon OSD T&E group, the many sites for US test ranges and, to a very limited extent, from the Web sites of the UK MoD. These generally point to each other.

Reynolds[1] has given a fine introduction to the general philosophy of master-planned T&E. The US DoD teaching book, Defence Systems Management Center (DSMC)[5] takes the reader further. It is currently under major revision. It is not openly sold. US DoD[6] instruction gives the official process. A basic course on the 'Principles of T&E' was developed through the DSMC text mentioned above leading to the contracted offering of Georgia Tech.[7], that took the materials out into the civilian arena. It was taken up by ACTE where it became a mature set of notes[8]. Other teaching documents are short course notes of Reynolds[9] and Hoivik[10] and their own US offerings. The thesis of Dvorak[2] is also useful, as it studies the various T&E processes.

These versions have been developing over the last 10 years and are now reasonably mature. However, the nature of T&E is that it is not a fixed process. So, there is need for those using it to develop their own support materials and lectures.

9. RESULTS & DISCUSSION

A short paper can only whet the appetite for more on master-planned T&E. Reynold's book is the best introduction todate[1]. It has been written for those who need to learn why the master-planned T&E process is needed across major engineering programmes to help reduce the risk of not reaching the required performance. He makes it clear that whilst the new paradigm did develop in defence programmes, it already finds applications in many civilian areas.

The process described here is applicable to any programme where resources are being applied to achieve certain goals. After investigation of current practices in land management using the environmental impact statement (EIS) to control development risk, ACTE staff are adapting the master-planned T&E processes for use in land programmes in Australia. The T&E process promises much better control compared with the EIS method.

The ACTE is also successfully applying the process to a major Europeon research programme i.e. systems engineering data representation exchange system (SEDRES) that is applying research to develop an improved system engineering data-network used cooperatively by five major EU aircraft designers and manufacturers. Another area in which it has been found useful is alongside the already existing quality assurance model used in software development. However, it is now necessary to state a word of caution. The reality is that the master-planned T&E process is still not the perfect answer. It alone will not guarantee that acquisition programmes will always deliver the performance called for. The appropriate T&E process has to be set up to suit the type of acquisition and national attitude. It has to be well accepted. It is also important to control other aspects, such as the systems engineering process, human personnel issues and political perturbations.

Australia has just begun to rebuild its defence capital procurement process, possibly incorporating master-planned T&E within it. It appears that the MoD, UK, and EU countries, in general, have yet to recognise that this paradigm is different and that it is needed. In the US, it is clear that they are also adapting the process to suit the fast changing acquisition processes now seriously replacing the time honoured waterfall methodology, such as evolutionary, incremental, phased, dual-process, gemstone, etc. to allow for commercial-off-the-shelf (COTS) products and the new practices of integrated product teams (IPT).

There are many reasons for giving serious consideration to the introduction of master-planned T&E. The main reason would be that without it a programme can all too easily fall behind schedule, will cost too much, or, even worse, not perform at all, as was the case with the Vasa.

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