2006 CCRTS
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TEPI: A NOVEL SOLUTION TO ICT TECHNOLOGY ROAD MAPPING

Topics: C2 Concepts and Organisations

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Abstract

Technology road mapping is a well known process for charting the development of technologies and their markets. By mapping a technology's maturity against time, road maps enable organisations to make the right technology investment decisions. Most road maps appear like 'Gantt charts', where key events are pinpointed to an exact date. It is considered that this type of road map is inadequate for mapping the development of ICT technologies, which are intrinsically dynamic and subject to change. It was therefore decided to construct a new and unique form of technology road map to address these problems. This was intended to provide the UK Ministry of Defence (Director of Equipment Capability - Command Control and Information Infrastructure), with a realistic view of prospective developments in the ICT field. This prompted the development of the 'Technology Exploitation Probability Index' (TEPI) - a novel solution to road mapping based upon measuring the probability of technology maturity against time. The TEPI aims to provide an estimate of the likelihood that any given technology will be available for insertion into a specified military programme at a given time. This paper analyses the processes undertaken in generating a TEPI and details its component parts.

1 Introduction

It is the commonly accepted practise of the UK Ministry of Defence (MOD) to utilise Commercial Off The Shelf (COTS) technology whenever possible. The use of COTS technology allows MOD to save time and money developing new defence systems and to take advantage of the huge amounts of research and development being undertaken by the commercial sector. The MOD Command and Control (C2) domain is one particular area where the use of COTS Information Communications Technology (ICT) technology is especially prevalent. Commercial ICT research is significantly better funded than MOD's ICT research - MOD spends approximately £450 million on all aspects of (non-nuclear) research each year, Microsoft alone spends £800 million per annum solely on software research and development[1]. The disparity in funding between MOD and the commercial sector means that any attempt by MOD to build a bespoke ICT system will most likely result in a more expensive and lower performing system than its COTS equivalent. MOD recognises this fact and therefore where possible, much of its ICT procurement is based upon COTS technology.

[1]Director of Technology Development, MOD: *'Computing: Its future and its impact on defence'*. http://www.mod.uk/linked_files/issues/scitech/Computing.pdf

There is no doubt that COTS ICT technology has many benefits, including cost and time saving. There are however, many challenges. Commercial ICT technologies are most often designed for use in static, benign environments where factors such as ruggedness and bandwidth are not an issue. Many pieces of ICT technology will perform badly in a deployed environment unless modifications or compromises are made. Another problem is the difference in timescales between the average MOD project length and the shelf life of a commercial product. Most MOD systems take several years to procure and will have a service life of decades - most ICT products and applications are refreshed every couple of years. MOD can successfully handle the obsolescence of individual ICT products by replacing them with functionally similar items (for example, there is little problem in replacing an out-of-date PC with a newer and faster model). Where problems do occur is when an entire technology is superseded. An example of this would be the movement from tape to floppy disk to USB memory stick as the preferred method for removable data storage. Each new technology in the example above has replaced the previous generation and none are backward compatible.

When procuring COTS ICT technology, MOD needs to maintain an awareness of developments and trends in the ICT industry:

- Will the technology work correctly when operating within the constraints of a military environment?
- If not, how much of an issue it will be to rectify these shortcomings?
- What are the potential future replacements for this technology?
- How long it is likely to be before this technology has a major refresh or is superseded and replaced?

One part of MOD that procures large amounts of COTS ICT is the Director of Equipment Capability - Command Control and Information Infrastructure (DEC CCII). DEC CCII's mission statement is to:

> *'deliver optimised, integrated, timely, Command and Battle Management (CBM) and Global Information Infrastructure (GII) equipment capabilities that meet stakeholder requirements within a coherent, balanced and cost effective investment programme.'*[2]

As DEC CCII operates in areas where there is much scope for utilising COTS ICT hardware products and software packages it is at risk from the above problems. To help DEC CCII to maintain awareness of ICT technologies QinetiQ undertakes an activity known as 'Technology Tracking'. This activity has been ongoing for the last 10 years and aims to *'actively watch, track and assess technologies and trends in the commercial marketplace, academia and other military organisations'*.[3] Technology Tracking is designed to help MOD and specifically DEC CCII by:

- **informing MOD at the earliest opportunity of emerging technology that could impact its business** - Technology Tracking aims to provide MOD with an awareness of new technologies that may have either a positive or negative effect upon their operations;

[2] MOD: *'DEC CCII Capability Area Plan'*, Presentation, May 2004.
[3] O'Dell, M.A., QinetiQ: *'Technology Management and Horizon Scanning'*, December 2005.

- **providing technology analysis** - the analysis provided aims to take into account the key differentiators that make MOD unique compared with other organisations. These include factors such as 'operating with limited bandwidth in hostile environments' and the need for multi-level security domains;
- **covering the many viewpoints that need consideration when analysing technology** - the analysis aims to contemplate factors such as functionality, performance, reliability, maintainability, evolvability and wider market dynamics.

The Technology Tracking programme continues to provide MOD with easily accessible reports on emerging ICT technologies and trends. However, it does not provide highly detailed predictions of future technological developments. DEC CCII requires a better awareness of the future prospects of particular technologies to help them to decide when, or indeed if, a technology will become sufficiently developed that it can be exploited as part of a military system. The logical vehicle to provide this level of prediction is a technology roadmap. A technology roadmap represents the predicted development of a technology or a group of technologies as it matures from research through to commercially available product. To this end, QinetiQ was tasked by DEC CCII to produce a series of example technology roadmaps.

2 'Gantt Chart on Steroids'

Generating accurate technology roadmaps is a difficult undertaking, especially when dealing with technologies within the ICT domain. There are many different factors that influence the development of a typical ICT technology - some are easy to model and predict, some are seemingly random. Certain ICT technologies, such as processors and hard discs have their development driven by technological developments - manufacturers produce incrementally faster processors/larger hard discs which become widely bought and ubiquitous. However the largest influence on the development of most ICT technology is market penetration. Many technologically advanced ICT technologies have failed to achieve market traction and have subsequently disappeared, whilst some technologies that have been poorly received by analysts and the press have gone on to become hugely successful and to have a global effect. Market penetration is exceptionally hard to predict as it consists of hard-to-measure and volatile factors, such as fashion, Metcalfe's Law[4] and the presence of killer applications. The presence of industry hype further muddies the water: the ICT industry pumps many hundreds of millions of Pounds of marketing spend per annum into hyping their wares. Consequently there is little realistic analysis behind the predictions in the ICT press and by 'independent analysts'. Without being able to successfully deal with the market volatility and hype, predicting the future development of ICT technologies becomes tantamount to crystal ball gazing.

The QinetiQ Technology Tracking team critically examined the leading road mapping techniques to evaluate their ability to consider the uncertainty inherent in the ICT industry. Overall, the team was disappointed with the techniques they assessed and felt that the majority were lacking in two critical areas:

1. **Their inability to capture and display the uncertainty as to when a technology will be ready for exploitation** - Conventional road maps pinpointed key events to exact dates in time. Road maps contained predictions such as '*by quarter two of 2010 this*

[4] Metcalfe's Law states that *'the usefulness, or utility of a network equals the square of the number of users'* Boyd C.: *'Metcalfe's Law'*.

technology will be ready for use'. This fails to take into account any of market volatility and hype, which may effect the technology's delivery date;

2. **The lack of consideration as to the effects of market penetration** - Many of the road mapping techniques failed to take into account the effects market penetration will have on the future development of a technology. Technologies were considered from the point of view of being technically ready or not; no consideration was given as to whether that technology would succeed commercially.

These two shortcomings have the effect of ignoring many of the most significant uncertainties inherent within the ICT industry and leads to the production of highly rigid and fixed sets of predictions as to the future development of technologies. Many of the road mapping techniques produced maps so specific in their predictions that they were essential nothing more that Gantt charts on steroids. None of the commercial road mapping tools could produce a roadmap that provided the information required by DEC CCII. This led the QinetiQ Technology Tracking team to develop their own road mapping technique - the Technology Exploitation Probability Index (TEPI).

3 The Technology Exploitation Probability Index (TEPI)

The TEPI was created by the QinetiQ Technology Tracking team with the intention of providing a road mapping tool that could successfully display some of the uncertainty endemic throughout the ICT industry. To achieve this, the TEPI utilises a 'window of opportunity' approach. Rather than tying a technology's level of development to a particular point in time, a window of opportunity allows a technology's state of development to be displayed as being between four points: the highest and lowest likely levels of development and the earliest and latest that this is likely to happen. Coupled with this window of opportunity is a probability index. Each point of the window is given an index that conveys the' level of confidence' that a technology will have reached that level of maturity by that point in time. Between the two of them, these windows of opportunity and probability indices allow the best and worse cases to be displayed, along with an indication of how likely they are to occur. The two differing approaches are illustrated below in Figure 3.1.

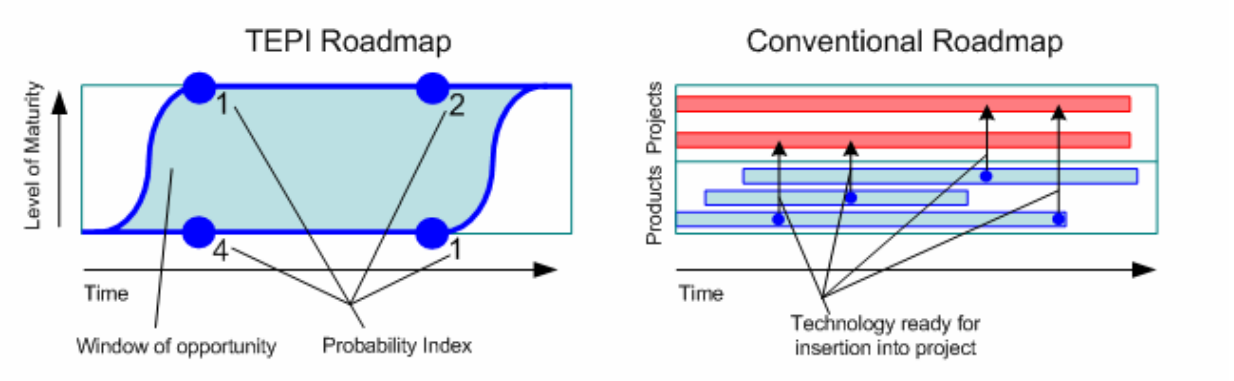


Figure 3.1 - A demonstration of how a TEPI represents maturity with a probability biased window of opportunity.

A TEPI road map is generated by using a set of predictive modelling techniques and input from relevant Subject Matter Experts (SMEs). The modelling techniques are primarily used to take

account of market factors that influence the prospective development of a technology. They include:

- product and market lifecycles[5];
- hype lifecycles;
- killer applications;
- displacement of existing technologies;
- fashion;
- legal / regulatory / political issues.

These predictive techniques are sufficiently reliable to allow the rationale for why particular probabilities have been chosen, to be explained. Currently these predictive techniques are treated as proprietary QinetiQ know-how, but the possibility of publishing them in the future is reviewed regularly.

The TEPI aims to provide MOD with a measure of the likelihood (probability) that any given technology will be available for insertion into a specified military system or programme at a given time. It gives MOD immediate insight into the 'windows of opportunity' where a particular ICT technology will be available for technology exploitation. The TEPI can map the development and evolution of technology prospectively or retrospectively. The mapping of technology retrospectively can help the user understand why the roadmap makes particular predictions about the future development of a technology. The TEPI can be used to follow market changes and trends, track the maturity of individual technologies or represent a hybrid of the two.

A TEPI consists of two parts - the TEPI chart itself and a guide sheet. The guide sheet provides additional information and context to the graphical representation and aids its understanding. The remainder of this section explains each of the key features of the TEPI and introduce the structure of the supporting text. Figure 3.2 shows a typical TEPI chart:

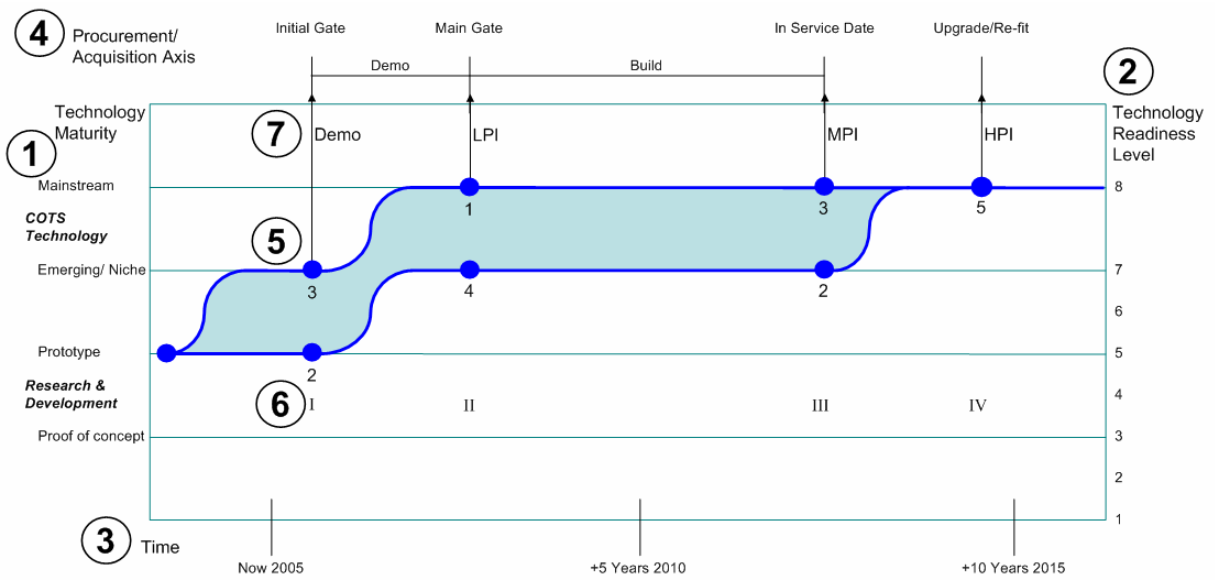


Figure 3.2: An example TEPI roadmap. The area marked in blue is the 'window of opportunity'.

[5] This predictive model is a derivative of the ground breaking work described by Geoffrey A. Moore in his book 'Inside the Tornado'. First published by HarperCollins Publishers Inc., 1995.

The TEPI attempts to encompass all the relevant information about the future development of a particular technology or market and includes details on key transitioning stages of development and any critical events which could have a particularly dramatic effect on a technology's progress. The individual elements of this diagram are described below:

1 – Technology maturity

The vertical axis on the left hand side shows the relative maturity of a technology and is known as the 'technology maturity axis'. This axis represents the level of development or maturity the technology has attained at a given time and is an indicator of its readiness for exploitation by MOD. The QinetiQ team has defined four levels of maturity that the technology can have, each one representing the different phases of development that the technology moves through as it transitions from lab prototype to a successful and widely used product:

- Proof of concept;
- Prototype;
- Emerging/Niche;
- Mainstream.

Proof of concept

Technology at this level is the least developed. Typically it will be technology that has only been demonstrated in a laboratory as technically feasible. Most technology at this level will still be under development in academic institutions and the research departments of ICT vendors. If sufficiently funded it is possible that these laboratory demonstrators could evolve into prototypes. However, there is also a good chance that many technologies at this level will not be developed any further.

Prototype

At this level the technology is still in development. Whilst it has moved beyond the lab based proof of concept, there is still much work to be done before it can be brought to market. This development work is typically either done by academic institutions with an eye to spinning the technology out into a separate company, or by existing manufacturers, who are creating prototypes of planned products. Once sufficiently developed, these prototypes can be commercially launched. Prototypes being developed by manufacturers have a better chance of becoming a commercially available product than those being developed by academic institutions.

Emerging/Niche

This phase encompasses two different types of development – emerging technology and niche technology:

- Emerging Technology - Technology that has just moved up from the prototype stage is an emerging technology. This technology has yet to become a commercial success and, as such, has limited market penetration.

- Niche Technology - Niche technology is technology that, whilst highly successful within a particular small market, has not successfully penetrated many other market segments. In the fullness of time, technologies at this level of

development typically either remain in their niche markets or gain in popularity and become mainstream technologies.

Mainstream
Technologies that reach this level of development are typically mature technologies that have been around for several years and have achieved a significant level of market penetration. Technologies that reach this level of development are usually established by new or existing market leading players who, barring any sudden wildcard technological developments, will be dominant in these markets for several years to come.

2 – MOD Technology Readiness Levels (TRL)
The vertical axis on the right hand side of the diagram delineates the MOD Technology Readiness Levels (TRLs). TRLs are used within the MOD procurement process to provide a quantitative measure as to how mature a technology is. This broadly corresponds with the 'Technology Maturity' axis already defined and although there is not a direct correlation between these two axes, a 'proof of concept' technology approximately corresponds to a MOD TRL of 3 and a 'mainstream' technology corresponds to MOD TRL 8. MOD TRLs are primarily aimed at bespoke rather than COTS technology.

3 – Timeline Axis
The bottom horizontal indicates time. Typically it is marked with increments of five years, although this could be increased or shortened depending on the nature of the technology or MOD requirements. The current time does not have to be at the far left of the axis. Roadmaps can be retrospective as well as prospective. On occasions it is sometimes worthwhile to show how a particular technology has 'evolved' in the past, as a view of the past often gives insight into the future.

4 – Procurement/Acquisition Axis
There is an option for a second time axis on the TEPI. If required, the top horizontal axis can be a project specific timeline. This project timeline is known as the 'Procurement/Acquisition Axis' and is intended to be used when a TEPI has been created for a particular MOD project or system. It is then possible to correlate technology with the key stages in the procurement cycle. These stages are listed below:

- Initial Gate;
- Main Gate;
- In Service Date;
- Upgrade/Re-fit.

The graphical representation of technology maturity against the procurement cycle provides MOD with an immediate understanding of where 'windows of opportunity' for technology exploitation lie.

5 – Probability index
Each point on the TEPI has a number that corresponds to it. This number is a probability index and is intended to convey the 'level of confidence' that experts have that the technology will be at a given maturity by a certain point in time. Higher numbers reflect a higher level of confidence. These are defined below:

- **1 – It is highly unlikely that this technology will have reached this level of development within the timescales in question.** With this level of probability it is not expected that the technology will have reached this level of development. However, due to the volatility of the technology industry, the possibility should not be ruled out.

- **2 – There is a small chance that this technology will have reached this level of development within the timescales in question.** At this level of probability the prospects of achieving this level of development are still low, although there is more of a chance this will occur than with a probability index of one.

- **3 – There is a reasonable chance that this technology will have reached this level of development within the timescales in question.** With a probability index of three the likelihood of the technology reaching this level of development are much improved. However, with a probability index of three, the likelihood of the technology achieving this level of development is no better than '50-50'.

- **4 – There is a very good chance that this technology will have reached this level of development within the timescales in question.** A probability index of four means that this technology stands a good chance of achieving this level of development, with a significantly improved chance over a technology with a probability index of three.

- **5 – Barring any potentially disruptive events and/or wildcard technologies, it is highly likely that this technology will have reached this level of development within the timescales in question.** This is the highest level of probability, and means that this technology is fully expected to reach this level of development. However, due to the uncertainty synonymous with the ICT technology industry and due to the possibility of alternate technologies being brought to market, there is still a chance, albeit small, that this technology will not reach this level of development.

6 – Key stages of development
At several points on the TEPI are Roman numerals. These are intended to mark key stages of development that are of importance during the lifecycle of the technology. For each point there is a detailed description in the 'Guide Sheet' and within the 'Additional Information' page. This description is intended to supply the rationale behind the layout of the roadmap at that point. This description also provides some background as to what is happening in terms of what key market players are likely to be doing at that point in time.

7 – Probability of Insertion
As the technology develops, the likelihood of it being possible to insert it into a project increases. At key points in time one of the following indicators can be used to state how ready for insertion the technology is likely to be:

- Demo – Technologies that are either at the late prototype stage or are emerging technologies that are ready to be demonstrated. These technologies are likely to have particular shortcomings, be it the durability of the technology itself or its likelihood of long-term market presence, but can still be tested as part of an

evaluation process to determine whether or not this technology will have any use in a project.

- Low Probability of Insertion (LPI) – This is the first point by which the technology may be mature enough to insert into a project. However, there is a only a low probability of the technology being mature enough at this point to enable insertion – this is just the earliest possible time by which it might be ready.

- Medium Probability of Insertion (MPI) – As the likelihood of the technology being mature increases, so too does the probability of insertion. The technology stands a middling chance of being mature by this point and therefore has a medium probability of being ready for insertion.

- High Probability of Insertion (HPI) – With some technologies there is a virtual guarantee of them becoming fully mature and mainstream by a given point in time. At this point there is a high probability that they can be inserted into a project.

Guide Sheet
Attached to the TEPI is a guide sheet. This sheet contains the background information on the technology, an explanation of its key stages of development and recommendations on how to proceed with the technology. This sheet is designed as a companion for the TEPI and its role is to guide end users through the graphical representation. It should be stressed that this text is an essential element of the TEPI and the two are inextricably linked. The sheet also contains a brief synopsis of the more detailed research that was conducted during the construction of the TEPI. This more detailed research or 'additional information' is also provided with the TEPI roadmaps.

Additional Information
Accompanying the TEPI is a section providing additional information. This section contains considerably more detail that the guide sheet and delivers the complete analysis that defined the TEPI. Briefly it contains:

- Key stages of development for this technology – this supplies the rationale behind the layout of the TEPI at given points;
- A description of the technology – including its shortcomings, potential uses and disruptive technologies that might affect this technology's development;
- Recommendations on how to proceed with this technology – should MOD consider inserting this technology into a project or is there little chance it will be mature enough for use within the available timescales?
- A list of market considerations that have the ability to affect the development of the technology;
- A list of vendors selling or planning to sell this technology and organisations currently researching it.

4 The Future

It is planned to further develop the TEPI roadmap and add it as the technology dimension into DEC CCII's view of its capability, equipment lines and its research programme. It is anticipated that the TEPI will play an integral part in alerting MOD to potential ICT technology solutions and threats to 2015 and beyond. This will support future proofing and timely technology insertion to meet MOD's current and future capability needs.

5 Summary

The QinetiQ Technology Exploitation Probability Index (TEPI) is a unique form of technology roadmap that has been designed to provide MOD with a realistic view of prospective developments in the ICT field. The TEPI is different to conventional roadmaps because it has been explicitly designed to capture the uncertainty inherent in the ICT domain. Its unique approach of measuring the probability of technology maturity against time provides MOD with insight into ‘windows of opportunity’ for future technology refresh and insertion. It is anticipated that the TEPI will play an integral part in alerting MOD to potential ICT technology solutions and threats to 2015 and beyond.

Acknowledgements

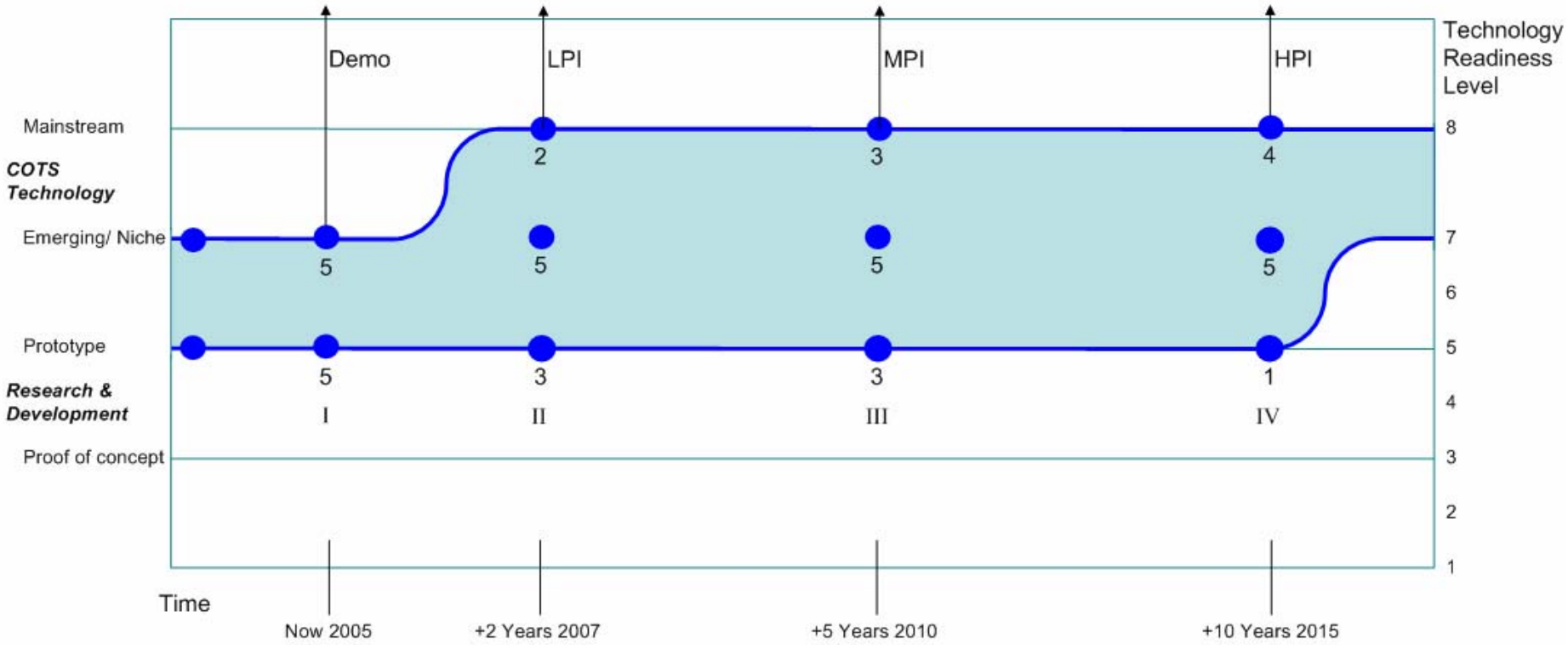
Dr Nic Peeling, Technology Assessment Group, QinetiQ
Dr Maurice Stanley, High Performance Visualisation, QinetiQ

6 Annex A - Example Road Map and Guide Sheet

Below is an example road map and guide sheet taken from the Technology Management Pilot Study conducted by the QinetiQ Technology Tracking team in December 2004.

Technology Category: **Display Technologies** Roadmap Type: **Technology Roadmap**

Technology: **Desktop Autostereoscopic 3D Displays**



Desktop Autostereoscopic 3D Displays

Description:

Desktop autostereoscopic displays are one form of 3D display technology where the user sees a 3D image without the need for glasses or any other device. There are several different kinds of autostereoscopic 3D displays and the displays covered by this roadmap are desktop models constructed out of LCD panels. Using a variety of different optical techniques (lenticular lenses, parallax barriers, multiple LCDs, etc) a slightly different image is sent to each eye, resulting in the user seeing a 3D image without the need for special glasses.
The images for each eye converge on a certain location known as a 'sweet spot'. For the user to see this 3D image they must position their head in this sweet spot, which is typically only a few cm across. To allow the user to move around many displays now include a built-in head tracker. The tracker determines the position of the user's head and constantly alters the two images to ensure that the sweet spot moves as the user moves their head.

Key Technical Issues:
The underlying LCD technologies currently run at resolutions that are perfectly adequate for 2D use. When displaying 3D images using this technology, the resolution of the 3D image is half that of the display. This makes the resulting 3D images of a significantly lower quality. At present, most of these displays only produce one sweet spot, and due to the small size of this spot, only one person at a time can use one of these displays. Some displays offer multiple sweet spots, but doubling the number of spots again halves the resolution of the 3D image, further reducing quality. With the head tracking displays the presence of other people nearby can confuse the tracker, resulting in the loss of the 3D image. Some of the displays with head trackers have moving parts that are susceptible to damage by vibrations and impacts.

Potential Uses for MOD:

These displays are ideally suited to the display of GIS information and will certainly prove useful for mission rehearsal applications by enabling mission fly-throughs.

Disruptive Technologies/Wildcards:

Volumetric displays, Holographic displays.

Key stages:

I - Currently several large manufacturing companies such as LG and Philips are developing prototype versions of this technology. Other manufacturers (Sharp, SeeReal, Dimension Technologies), are selling commercially available products, although these are aimed at niche markets and have achieved little in the way of mainstream market penetration.

II - Within two years several companies, such as Sharp, with support from the 3DConsortium will probably make an attempt to push this technology into mainstream use. There is a fairly low chance of success at this point, although it should not be ruled out. The niche markets for this technology will still be strong, but fewer companies will be undertaking R&D.

IIII - Within five years it should be clearer as to whether or not the attempted push towards the mainstream was a success. In the event of failure, this technology will still be strong in niche markets but will still not have achieved mainstream success. There will be a fair chance that another push into the mainstream will be planned for the future. As before, the niche markets are still likely to be strong and a further reduction in the number of companies undertaking R&D is likely to have occurred.

IV - By ten years, if necessary, another attempt at gaining widespread market success is likely to have been made. This attempt is more likely to succeed due to improvements in technologies such as the resolution of the LCD displays. Even if this attempt fails, the niche market for this technology will still be strong; however, it is now unlikely that there will be any companies involved in just research of this technology.

Recommendations:

This technology is mature enough to demonstrate at this time. We would not recommend planning to insert this technology within the next few years as it is unlikely to be mature enough. However, we would recommend planning to insert this technology within 10 years.