



## MONET2

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### Fault Detection and Diagnosis (BRIDGE) Technological Roadmap (Version One)

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# 1 Introduction

## 1.1 Purpose of this Document

The Bridge Task Group is aimed at further developing, relating, or converging the various approaches of FDI (Fault Detection & Identification – Engineering / Control field) and DX (Diagnosis - Computer Science / Artificial Intelligence field) to the diagnosis of technical systems, in combination with relevant conferences and industrial participation. The Task Group has defined a set of problems extracted from industrial concerns supplied by industrial participants, and works by analysing the application of the respective technologies to the formation of solutions to industrial problems, thereby assessing their strengths, weaknesses and also their general complementarity.

## 1.2 Objectives

The Task Group has the following objectives;

- To support the transfer of model-based diagnosis (MBD) technology into industry related disciplines
- Through industrial participation, to help identify for participants from different backgrounds, the requirements of the diagnostic processes in industry, and to relate the existing theories, methods, techniques and systems to these requirements
- To determine and define problems extracted from industrial challenges, and to use these as tests for measuring and comparing the value and the results of applying various techniques or combinations thereof in the search for solutions
- To compare and characterise the presumptions and scope of applicability of MBD technologies developed in control theory (FDI) and AI (DX)
- To identify competing and complementary methods and solutions using the DX MBD technology alongside the FDI MBD technology
- To identify and define useful interfaces and protocols for beneficial combinations of techniques

## 2 Present Situation of Technologies

Technologies, such as those used in DX or FDI, have always faced issues when it comes to the realisation of real world applications.

End Users often do not have a clear understanding of the technologies<sup>1</sup>. Hence, it should be our responsibility to ease the transfer from our research field to 'Technology Supply Companies'. At this time, and in the Bridge context, it is clear that FDI techniques are more established and are better known by engineers than their DX equivalents. Hence, one of the main long term goals of Bridge should be to provide those companies with prototypes / products combining both technologies.

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<sup>1</sup> It must be noted that within the field the term 'Users' is split into two distinct groups. Business / End Users are the people who utilize the applications that are produced using this technology. It is the suppliers of the applications, the 'Technology Supply Companies', who are the ones who make the transfer of the technology from development to product and it is these companies to whom the 'technology' itself must be justified. The Business / End Users often do not care, or usually even know, what technology underlies the products they are using.

This situation is also a consequence of the current state of the research world; where there could be conflicting, or even opposing, ideas or understanding of the same issues. It has been the task of Bridge to attempt to bring these people and ideas together in order to find common ground, although it has struggled against the lack of momentum from the FDI community to accept DX technologies. This is, however, a situation that can often occur when researchers focus closely on their own particular fields of expertise and do not work in wide collaboration with researchers from different backgrounds. This degree of research specificity is required both to forward research aims and also for many of the important aspects of complex problem solving, where certain approaches can lead to better results than others. However, the critical importance of bringing different, but associated, research communities together can be seen when there are issues in one community that could be better solved by the methods in another. Examples do exist which can clearly demonstrate that this is in fact the case, e.g. the successful introduction of fuzzy logic or neural networks in control technology; the use of statistical techniques in FDI; the use of dynamic systems theory result in qualitative reasoning, etc. Fortunately, there are now more researchers who are aware of the variety of available diagnostic techniques and it is Bridge's intention to ensure that this spectrum of techniques should be applied more often in the future. Many researchers in the DX field already benefit from the utilisation of some FDI technologies but the reverse is not generally true.

Another primary challenge which the MBD (and any other diagnostic) community is facing, is that the complexity of modern systems is increasing vastly quicker than its current ability to model these systems. One source of complexity is that there are systems with a large number of components / distributed systems, etc. Although there are current efforts devoted to these issues (works based on agents, or distributed aspects of diagnosis), additional research is needed. Another issue is that larger systems will have more kinds of uncertainty, noise and unknown disturbances related to model building issues which exist in both FDI and DX. If these issues are to be solved, a combined (hybridised) approach must be adopted. It has been shown that one technology can be better suited for a given kind of problem than another, and vice versa. For instance, FDI is more suited and has larger experience of fault detection than fault localisation, while in DX fault detection is usually taken for granted and emphasis is placed upon fault localisation. Hence, many diagnosis applications would require the complimentary use of both techniques. Nevertheless, in order to share results and techniques, there should be a common framework and a common understanding. This is another major goal of Bridge.

Both FDI & DX techniques have restrictions when facing real, complex problems and thus have to make assumptions (single fault, etc.). This is less of an issue in DX, which means there is the potential for FDI to benefit from this approach. However, if we are to demonstrate the compatibility of these techniques, there is a need for a product(s) that will show that DX and FDI technologies can be combined and applied in real world applications. Identifying what problems exist on the road to generating this application would lend considerable weight to the efforts to combine the technologies.

Another factor that would be of considerable value would be to show how Model Based Reasoning (MBR) can benefit from complementary techniques in order to cope with diagnosis of complex systems. It is also important that the technology above MBR is able to extract relevant pieces of information, data, parts of models, etc. and fully understand and interpret them. However, it is likely that when diagnosis is difficult it will always be difficult and that there will always be some systems which are too complex and need to be diagnosed using simplified models. It is very hard to say if this will always be the case or not.

Summarising, BRIDGE aims are to provide a better understanding of each other for both DX and FDI communities; then bring in a common framework which would allow future sharing of the best from both worlds (results and techniques); and helping in the transfer of these

results, with new products (for instance, ToolKit Products) that can smoothly combine both approaches.

### **3 Roadmap**

Bridge is focused very closely on 'bridging the gaps' between the FDI and DX communities. In order to do this, as clear a picture of these gaps as possible must be drawn up. For the Technological Roadmap to successfully assist with this task it must be more general in application, and concern itself with the whole technology of Diagnosis and not just with one particular area of it. The Bridge Task Group can then utilise it to forward the aims of the Diagnostic community as a whole by using the best of both techniques in the future under a common framework.

Initially, however, the Roadmap will examine the State of the Art in the sector and draw upon the current position of the Technologies in order to attempt to predict future trends. It should be considered that within the Diagnostic community, FDI is more established than DX. Nevertheless, we cannot be certain as to whether there will be a time when the two are at the same stage of development or whether FDI will continue to develop at the same pace and will therefore always be ahead of DX.

The technological aspects of the field can be divided up according to their level of technical complexity:

- Modelling Issues
- Temporal issues
- Diagnosis and Product Life Cycle
- Autonomy versus human interface in applications

#### **3.1 Modelling Issues**

Currently there are very few domain libraries which exist, and these are only in a very few application domains. In the near future however, more domain libraries should be available. Moreover, a considerable effort should be devoted to improving automated modelling, thus diminishing the dependency on human experts and paving the way to solve all the variants of a problem. For this trend to occur successfully there would also be a need to combine models from both MBR and other technological approaches, one example of which would be machine learning.

There are still several diagnosis solutions which are based on simplifying assumptions (such as single fault or non-compensation assumptions) in order to be effective and / or efficient enough for real world applications.

Furthermore, the ever increasing complexity in systems pushes the need for new diagnostic solutions. For instance, there are problems associated with the distribution of diagnosis in complex systems. FDI approaches the system as a whole, and therefore misses concepts so that tasks are shared. Current diagnostic technology only utilises one core part, to be in a position to work on distribution may take another five years.

### **3.2 Temporal Issues**

Currently, 'time' is only included in models of dynamic behaviour. Nevertheless, there are at least two additional temporal aspects that should be considered in future diagnosis systems. General theories and techniques are to be developed that handle problem characteristics such as intermittent faults, dependant faults and exploiting information across time, that go beyond current area / system-specific solutions. There are also no general approaches to diagnosing time-varying systems.

### **3.3 Diagnosis and Product Life Cycle**

If Diagnosis is to have a real and continuously improving effect on the performance of real world systems, it must be integrated with other high-level tasks, such as monitoring, planning, reconfiguration, and so on.

Also, Diagnosis should be considered in the whole product life cycle, from design to maintenance. For instance, diagnosis is not currently considered at the design stage. Diagnosability analysis can be highly valuable at this stage and produce key design requirements.

Additionally, models themselves need to be considered in the whole product life cycle. The models used would need to be changed, adapted, updated and re-configured.

Finally, there will be a whole spectrum of possibilities that arise from using a set of diverse techniques in combination with MBR.

### **3.4 Autonomy versus Human Interface in Applications**

In the near future, there should be a set of Diagnosis Toolkits available for the Technology Supply Companies, containing MBD techniques (with the best from both MBD communities) within a common framework. This fact could also ease the process of integrating Diagnosis with other high-level tasks in real applications.

Diagnostic applications must interface with human beings. Currently, monitoring merely produces a report for an operator, i.e. the system simply activates an alarm. A considerable amount of human intuition is still required to interpret these alarms. Modern diagnostics does, however, reduce the processing time of the human operator by providing more information and not just an alarm, of which there can often be a vast number. In the future diagnostics will be used to alert an operator to the fact that the alarm has occurred and produce a diagnosis of any possible fault. Eventually this would lead to the eradication of 'alarms' - instead we would have an autonomous system which identifies and corrects the fault itself and merely informs the operator that this has been done. This is an 'ideal' scenario and in actuality there may be a need to stop the machine to reconfigure. Although the diagnostic report could include instructions on how this can be done by the operator.

There are people who believe that there are some domains in which systems are improving and operators are becoming less significant. Many systems still rely heavily on the ability of a human operator, but as systems become more complex it is becoming harder to train experts with all the relevant technical information. Research is being done into the possible removal of operators from a system entirely. It is envisaged that this may even be possible in 'Critical Domains'. There is a great deal of interest in research in unmanned operations in areas such as Satellites; there have even been demonstration models built but it may still be 10 years before any real world applications are available. However in areas such as Nuclear

Power Plants it is considerably harder to say when (or if) an unmanned system would be possible, let alone acceptable.

As a motivating example, we mention an application in the Automotive Domain: ADAS (Advanced Driver Awareness Systems); see for example the European project AWAKE (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation, <http://www.awake-eu.org>). This is a diagnostic system which is designed to ensure the continued alertness / awareness of a motor vehicle driver. This system uses the necessary wireless support mechanisms needed to deliver the co-ordination of on-board and off-board systems, which has proved necessary due to restrictions of using solely onboard systems.

This application identifies single faults in a system and can inform the driver of these issues. However, it also deals with the possibility that if the driver is tired they themselves then become the 'fault'. For this diagnosis to be workable, problems have to be recognised before they can be diagnosed. You then need to define state assessment, which needs to be formalised and the system adjusted. It may be possible to approach the situation from the data, and then model it. The one problem with taking a statistical approach to diagnosing systems is that many sensors are required in order to gather sufficient data for statistical analysis.

## 4 Graphical Roadmap

Now	2 Years	5 Years	10 Years
<p>1. On board / Off Board Debate</p> <p>2. Cannot easily Integrate MBR and MBD within engineering environments (Problem 5 years ago and still a problem).</p> <p>3. Model Building Technology not yet available.</p> <p>4. Systems often too complex to train engineers</p> <p>5. Internet Support</p> <p>6. Too many 'No Faults Found' or 'Hard to Diagnose' Systems. Very expensive to support.</p> <p>7. Use of multiple level models</p>	<p>1. Integration of Diagnosis and other Tasks.</p> <p>2. Wireless Communications</p> <p>3. Managing Multiple fault detection, due to the interactions between different systems (e.g. automotive domain).</p> <p>4. Industry has too many processes that require DX techniques for the first time</p> <p>5. System variants limit application of DX techniques. Consistent with model based approach?</p>	<p>1. Need to obtained a sound explanation of what is going around (DX Conf. may provide some of this)</p> <p>2. Customers expect customised products (variants) at low cost.</p> <p>3. Maintenance costs of systems start to become too high due to system complexity</p>	<p>1. Many systems need to be fault tolerant.</p> <p>2. Some systems can be automatically re-configured.</p> <p>3. Diagnosis smoothly integrates in a well defined supervisory system.</p> <p>4. Companies want to remotely diagnose and reconfigure (embedded) systems (because of complexity and wireless connections)</p>
<p>1. Systems so complex that diagnosis must be considered at design time.</p> <p>2. Users expect systems to be diagnosed and re-configured without returns to base.</p>			

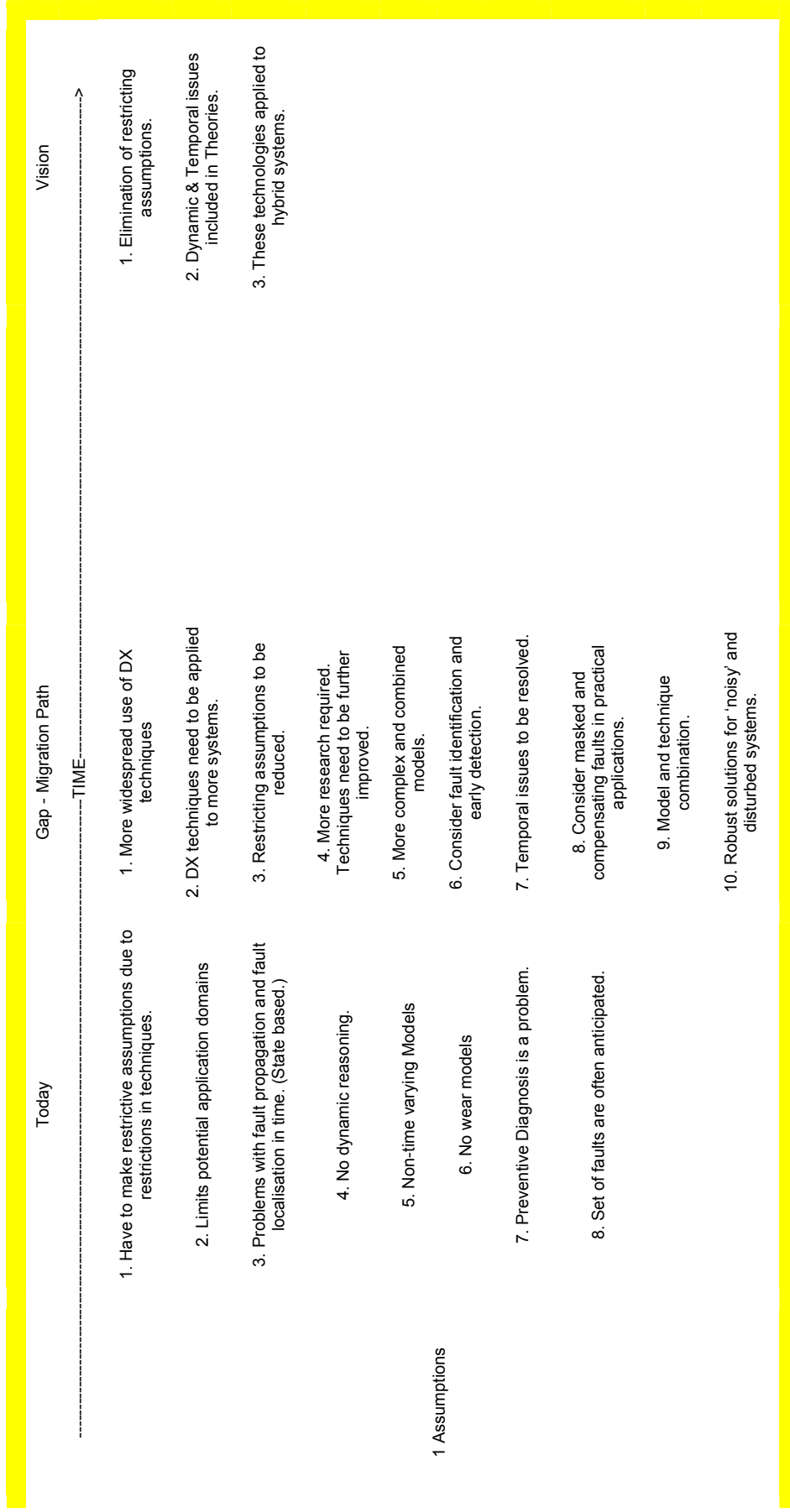
Drivers

	Now	2 Years	5 Years	10 Years	
<b>Products</b>	1. Not Distributed - Only one core part.	1. DX and FDI Techniques used together in 1 application	1. DX technique software product	1. Model based techniques become commercial valuable in 1 application area. Hence more people learn about it (Killer Application).	1. FDI techniques used by almost all companies in 1 sector for a specific task.
	2. System Alarms, i.e. fault detection - No diagnosis	2. DX techniques used as standard in 1 aspect of at least 1 application domain	2. Diagnose systems with lots of components	2. Diagnosis distributed in the system.	2. Automated DX in some Critical Systems (Satellites, autonomous systems).
	3. FDI Tool-kit Products	3. FDI techniques used as standard in 1 aspect of > 10 application domains	3. Key technology companies understand DX and FDI Techniques	3. Systems can go beyond only Alarms	3. Diagnosis systems can perform fault identification for complex systems.
	4. FDI techniques used in some commercial applications	4. FDI techniques used as standard in 1 aspect of > 10 application domains	4. Technology Supply companies can offer FDI and DX techniques	4. Re-Usable Model Libraries in 5 Domains	4. Systems are designed to make the use of DX techniques easy.
	5. DX techniques used in a few commercial application			5. Automotive Domain – Intercollaboration between different modules in a process. (Advanced Driving Assistance Systems - ADAS).	5. Re-usable model libraries in >20 domains.
	6. Diagnosis systems are limited to detection and localisation in complex systems			6. Automotive Domain – Optimisation of the entire on-board system (Common resources, communication, fault tolerance and recovery).	
	7. No products include FDI and DX as standard products				
	8. Connect of faults (re-configuration) is done manually.				
	9. Industry Applications are limited to techniques that suit FDI techniques				

Technology	Now	2 Years	5 Years	10 Years
1. System complexity restricted	1. Model updating Techniques	1. Applications with combined FDI and DX techniques	1. Common technological framework accepted	1. Diagnosis at the design stage - the only way to get models.
2. Re-usable libraries in only a few domains	2. Search and optimisation	2. Distributed diagnosis in automotive domain due to network introduction, in space applications (satellites constellations)	2. Relax single faults assumption.	2. Problem characteristics not a major limitation.
3. Can only model engineering domains of medium complexity		3. Diagnosis as state estimation within a whole fault tolerant / automated architecture	3. DX Critical demonstration	3. DX as the reasoning core of the diagnosis tasks, providing a framework to integrate other techniques.
4. Restricted compatibility if time-varying system			4. Models from both systems – data and mathematical techniques.	4. Diagnosis integrated in a well defined supervisory system.
5. Diagnosis as state estimation in a very few systems.				5. Reorganising the cycle Design - On board Diagnosis - Maintenance.
6. Diagnosis not done at the design stage				6. Temporal issues may be addressed.
				7. (12+ years) some systems still too complex.

	Now	2 Years	5 Years	10 Years
<b>Resources</b>	<p>1. Many Universities teach FDI techniques (Ph. D. MSc)</p> <p>2. Only specialists learn of FDI and DX techniques</p>	<p>International Joint Conference on Diagnosis: MBR + KBR + CBR+ ML + signal processing ... through different domains.</p> <p>1. Funding, NoE, IP on diagnosis.</p>	<p>1. Many Universities teach DX Techniques.</p> <p>2. Majority of Engineers learn about FDI techniques.</p> <p>3. Architectures Integrated by – Fault detection and Diagnosis + Tolerant Control + Maintenance.</p>	<p>1. Universities teach FDI and DX techniques together (Ph D, MSc)</p> <p>2. Majority of Engineers learn about DX techniques.</p>
		<p>1. Summer School with both techniques</p> <p>2. Technology addresses both approaches</p> <p>3. Systems are more and more complex and can not be described by only one type of model. FDI techniques have to be adapted to these non-equal models</p>		

## 5 Technology Gap Migration Roadmap



<p>1. Currently FDI, DX, with Bridge in between.</p> <p>2. Potential for DX to be absorbed by FDI as it is so small.</p> <p>3. Tech companies know FDI, but don't know DX.</p> <p>4. No agreed terminology.</p> <p>5. People in industry understand one technique but not the other – limited technological cross over.</p> <p>6. FDI taught at Under-grad level. DX taught only at Post-grad Level.</p> <p>7. FDI people do not use DX, but DX Community beginning to look at FDI.</p> <p>8. No 'Diagnosis Community' in AI (unlike FDI for engineering)</p>	<p>1. Core techniques need to be combined.</p> <p>2. People need to understand the other set of techniques – possibly need to teach both techniques at an earlier stage.</p> <p>3. Better characterise the best techniques for more classes of problems.</p> <p>4. SafeProcess co-located with DX again.</p> <p>5. Key research groups need a common understanding.</p> <p>6. Identify common areas.</p> <p>7. Key researchers to use both sets of techniques.</p> <p>8. Key Conferences have papers using both techniques.</p> <p>9. Leading edge technology supply companies understand FDI and DX techniques.</p> <p>10. Leading Professors (5 of) in the field tackle difficult problems that require both FDI and DX techniques.</p> <p>11. Hybrid systems development drives the union of FDI, DX and related.</p> <p>12. FDI and DX Summer School for major players in fields.</p> <p>13. Requirement for funding in Europe.</p>	<p>1. Technical Support Companies would offer both techniques.</p> <p>2. People would understand both techniques and use them (as well as combined techniques).</p> <p>3. Maintain 2 communities with a good communication system and superb understanding of one another's techniques.</p> <p>4. One common conference for the whole Diagnostic community.</p>
<p>2 Diagnostic Community Understanding</p>		

<p>1. Bridge!</p> <p>2. Very few other attempts being made and these only in research world.</p> <p>3. Domains that require both technologies are limited with today's formulated requirements.</p> <p>4. Research world is far in advance of industrial world.</p> <p>5. People are beginning to diversify at present.</p> <p>6. Hybrid systems track offers potentially good opportunity.</p> <p>7. Very few diagnosis combined approaches (model based only)</p>	<p>1. Combined approaches will be required.</p> <p>2. Consider lessons learned from other AI techniques paths into FDI for integration of DX technologies.</p> <p>3. Links and common concepts need to be explored further. Leading Profs. to address problems in both areas.</p> <p>4. Example problems and results of the common ground need to be found.</p> <p>5. Compare different techniques on relevant reference problems.</p> <p>6. Extend DX/FDI techniques into other application domains and communities. Work with people from other communities with some areas of research.</p> <p>7. Need to demonstrate what DX can achieve for the other research communities.</p> <p>8. Need to be ambitious without moving too fast and losing researchers along the way.</p> <p>9. Should look at high level tasks such as 'Supervision', 'Monitoring' and 'fault tolerant control'.</p> <p>10. Provide DX examples in areas where FDI fails down.</p> <p>11. Common Terminology.</p> <p>12. Integration of techniques across application Domains.</p>	<p>1. To clearly identify and integrate the technologies so that more complexity and system autonomy and completeness wrt types of fault can be achieved.</p> <p>2. To be able to design fault tolerant systems and produce a better system state assessment.</p> <p>3. Smooth integration of diagnosis within higher-level tasks such as supervision</p>
<p>3 Integrated technology approaches</p>		

## 6 References

N/A

## 7 Document History

<i>Version</i>	<i>Date</i>	<i>Changes made to document</i>	<i>Changed by</i>
2.0	30 <sup>th</sup> June 2003	Task Group Produced Document	Bridge TG
2.1	3 <sup>rd</sup> October 2003	Updated with Standard format. Text remains unchanged therefore release date is still June 03	RIR