6 Literature references

Aitken, J. S., Schmalhofer, F., Shadbolt, N. A Knowledge level Characterisation of Multi-Agent Systems, Lecture Notes in Artificial Intelligence, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 179-190

Albright, R., Roadmaps and Roadmapping for Business Applications, Bell Laboratories, Lucent Technologies , 29 October 1998

Baldwin, C. Y., Managing in an Age of Modularity, Harvard Business Review, September – October 1997, 84 – 93

Barney, J. *Firm Resources and Sustained Competitive Advantage*, Journal of Management, 1991, Vol. 17, No. 1, 99-120

Bitondo, D. amd Frohman, A. *Linking Technology and Business Planning*, Research Management, November 1981, 19-23

Bongaerts, L., Jordan, P., Timmermans, P., Valckenaers, P. and Wyns, J. Evolutionary Developments in Shop Floor Control, Cooperation in manufacturing: CIM ate work Conference, Kaatsheuvel, The Netherlands, August 1995, 287-300

Brooks, P. F., No Silver Bullets, Unix Review, November 1987, Vol. 5, Iss. 11, 39-48

Brown, R. Peroxide Market Begins to Recover as Rationalizations Boost Pricing, Chemical Market reporter, May 17, 1999

Bushko, D., Raynor, M. *What futurists believe*, Journal of Management Consulting, Vol. 9, No. 3, May 1997

Bussmann, S. An Agent-Oriented Architecture for Holonic Manufacturing Control, First International Workshop on Intelligent Manufacturing Systems, Lausanne, Switzerland, 1998, 1-12

Bussmann, S., McFarlane, D. C., Rationales of holonic manufacturing systems, Paper presented at IMS 99, Leuven, Belgium, 1999

CAPE-21 Feasibility report, downloaded form http://cape-alliance.ucl.org.uk/ on 1 September 2003.

Chokshi N. N. and MacFarlane D. C., Rationales for Holonic Applications in Chemical Process Industries, V. Marik et al. (eds), Multi-Agent Systems and Applications II, , Springer-Verlag, January 2002, 336-350

EIRMA, Technology Roadmapping: Delivering Business Vision, report of EIRMA Working Group 52

Ekdahl, B., Astor, E., Davidsson, P. Towards Anticipatory Agents, Lecture Notes in Artificial Intelligence, Wooldridge,

J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 191-202

Ferguson, I. A., Integrated Control and Coordinated Behavior: a Case for Agent Models, Lecture Notes in Artificial Intelligence, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 203-219

Franklin, S., Graesser, A. Is it an Agent, of just a Program?: A Taxonomy of Intelligent Agents, Lecture Notes in Artificial intelligence: Intelligent Agents III, Muller, J. P, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-96 Workshop on Agent Theories, Architectures, and Languages, Budapest, August 1996, 21-36

Garcia, M. L. and Bray, O. H. Fundamentals of Tehcnology Roadmapping, Strategic Business Development Department, Sandia National Laboratories , April 1997

Garcia, M. L. and Bray, O. H. Introduction to Technology Roadmapping: The Semiconductor Industry Association's Technology Roadmppaing Process , Strategic Business Development Department, Sandia National Laboratories , April 1997

Garcia, M. L. and Bray, O. H. Technology Roadmapping: The Integration of Strategic and Technology Planning for Competitiveness, Proceedings of the Portland International Conference on Management of engineering and Technology, Portland, 27-31 July, 1997

Goldman, S. L., Nagel, R. N., Preiss, K. Agile Competitors and Virtual Organisations, Van Nostrand Reinhold, 1995

Grant, R. M. The Resource Based Theory of Competitive Advantage: implications for Strategy Formulation, California Management Review, Spring 1991, 114-134

Green, D. The Chemicals Industry, Financial Times, September 25, 1997

Groenveld, P. Roadmapping Integrates Business and Technology, Industrial Research Insitute, September-October 1997

Heikkila, T., Jarviluoma, M., Juntunen, T. Holonic Control for Manufacturing Systems: Functional Design for a Manufacturing Cell, Integrated Computer Aided Engineering, 1997, 202-218

Henderson-Sellers, B. A Book of Object-Oriented Knowledge, Prentice Hall, 1992

Hill, D., Operational excellence through collaborative manufacturing, Presentation made to the Honeywell User's Group (Americas), June 2002.

Horn, P. (2001) *Autonomic Computing: IBM's perspective on the state of information technology*, viewed at http://www.research.ibm.com/autonomic/manifesto/autonomic_computing.pdf on 1 September 2003.

Huang, J., Jennings, N. R., Fox, J. An Agent Architecture for Distributed Medical Care, Lecture Notes in Artificial Intelligence, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 219-232

King R. K., **Applying TRIZ and the Theory of Ideal SuperSmart Learning to Computing Systems: Ultimate Ideal Autonomous Objects, Strategic Problem Solving, and Product Innovation, viewed at http://www.triz-journal.com/archives/2002/09/e/ on 1 September 2003.**

Koestler, A., The Ghost in the Machine, The Macmillan Company, 1968

Lowe, S. EIRMA, Round Table on Technology Roadmapping, Paris, 5 February 1995

Mathews, J. Organizational foundations of object-oriented programming, Journal of systems software, 34, 1996, 247-253

McFarlane, D. C., Holonic Manufacturing Systems in Continuous Processing: Concepts and Control, Proceedings of ASI '95, June 1995

McFarlane, D., Matson, J. understanding, Measuring and Improving Production Responsiveness – A Control Systems Perspective, Proceedings of ASI '99, September 1999

Milner, J. M., McFarlane, D. C., Modularity in Production Systems: An Approach to System Design for a Turbulent Future, Institute for Manufacturing, University Of Cambridge, August 1998

Mjaavatten, A., Foss, B. A. A Modular System for Estimation and Diagnosis, Computer in Chemical Engineering, Vol 21, No. 11, 1997, 1203-1218

Moffat, D., Frijda, N. H., Where there's a *Will* there's an Agent, Lecture Notes in Artificial Intelligence, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 245-260

Muller, J. P. A Cooperation Model for Autonomous Agents, Lecture Notes in Artificial intelligence: Intelligent Agents III, Muller, J. P, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-96 Workshop on Agent Theories, Architectures, and Languages, Budapest, August 1996, 245-260

Phaal, R., Farrukh, CJP. and Probert, D.R. Fast-Start Technology Roadmapping, IAMOT 2000 Conference, October 1999

Probert, D., Farrukh, C. and Gregory, M. *linking technology to business planning: theory and practice*, International Journal of Technology Management, Vol. 18, Nos. 1/2, 1999

Ramos, C., Sousa, P. Scheduling Orders in Manufacturing Systems using a Holonic Approach, Instituto Superior de

Engenharia do Porto, Depertment Informatica, Porto, Portugal

Riel, J. A., Object-Oriented Design Heuristics, Addison-Wesley Publishing Company, 1996

Ryman and Cash

Stacey G. S. and Ashton, W. B. *A Structured Approach to Corporate technology Strategy*, International Journal of Technology Management, Vol. 5, No. 4, 1990, 389-407

Stephanopoulos, G. Chemical Process Control. An Introduction to Theory and Practice, Englewood Cliffs, NJ: Prentice Hall, 1984.

Stephanopoulos, G. and Han, C., Intelligent systems in process engineering: a review. *Computers in Chemical Engineering.*, **20**(6/7), 743-791

Swift, T. K. Where is the Chemical Industry Going, Business Economics, October 1999, 32-41

Teece, D. J., Pisano, G. and Shuen, A. *Dynamic Capabilities and Strategic Management*, Strategic Management Journal, vol. 18, No. 7, 1997, 509-533

Thompson, J. Technology Roadmapping – A New State of the Art, Lucent Technologies Inc., 27 October , 1998

Tullo, A. BASF Devises Nafta PS Strategy as Market Braces for Oversupply, Chemical Market reporter, July 6, 1998

Van Brussel, H., Bongaerts, J., Wyns, P., Valckenaers, T. G., Van Ginderachter, A Conceptual Framework for Holonic Manufacturing: Identification of Manufacturing Holons, Journal of Manufacturing Systems, Vol. 18, No. 1, 35-52

Van Leeuwen E. H., Norrie, D. Holons and Holarchies, Manufacturing Engineer, April 1997, 86-88

Willyard, C. H. and McClees, C. W. Motorola's Technology Roadmap Process, Research Management, September – October 1987, 13-19

Wooldridge, M., Jennings, N. R., Agent Theories, Architectures and Languages: A survey, Lecture Notes in Artificial Intelligence, Wooldridge, J. M. and Nicholas R. J. (eds), ECAI-94 Workshop on Agent Theories, Architectures, and Languages, Amsterdam, August 1994, 1-21

7 Appendix A Approaches to technology roadmapping

7.1 The Garcia and Bray (1997) process

This phased approach was developed for use in the semiconductor business. The environment in which it would be utilised was highly disciplined with regards to the organisational structures that supported the process.

The three phases of which this process consists is discussed below.

Phase 1 Preliminary activity

This phase is essentially about aligning the relevant role players by developing a charter for the process that follows. Its importance is often underestimated. It consists of the following sections:

- satisfy the essential conditions
- realisation of the need for a roadmap
- identification and obtaining participation of relevant role players, including research and development, production, maintenance, marketing, customers, suppliers, government, academia
- obtaining the buy-in of all those concerned
- Obtain sponsorship (The participation of a wide variety of role players accentuates the need for effective sponsorship. The sponsor drives the process and should ideally have a vested interest.)

- Delineate the scope and boundaries of the roadmap (This step provides a clear objective, deliverables and plan of action for the development of the roadmap. It enumerates the assumptions and dependencies on which the process is based. It provides a clear scope and may explicitly list aspects that are out of scope.)

Phase 2 Development of the technology roadmap

This phase is characterised by outlining the roadmap, obtaining the required data, structuring the data into roadmap building information and coherently integrating the information. The following steps are recognised:

- identification of the product (or process) that will be focus of the roadmap (Although the authors of this process do not note this explicitly, this is not a trivial step. It might be the outcome of an exhaustive process of scenario planning together with the identification of business needs)
- identification of critical product (or process) requirements and target levels of performance (This step specifies the critical attributes of the product (or process). These attributes are typically defined as the achievement of a defined performance target at a specified time (or in plural, the required performance improvement trajectory over time))
- identification of the strategic technology areas (The next step is targeting the relevant technology areas. These are the areas that will enable reaching the required level of performance and/or will be impacted on by the envisioned product (or process))
- specification of the technology drivers and their targets (The achievement of the desired system requirements are dependent on particular technology drivers in every

strategic technology area.. This step identifies these drivers.)

- Identification of technology potential technology choices and their time lines (This step identifies a list of technology alternatives that enable the achievement of the targets set for the technology drivers.)
- recommending those technology alternatives to pursue (From among those alternatives identified in the previous step, those that will be actively fostered are now selected. The selection process is analogous to that which forms part of the technology process and is not less rigorous. It balances cost with expected performance and schedule.)
- creation of the technology roadmap (The information obtained in the previous steps are now used to construct the roadmap.)

Phase 3 Follow-up activity

In this phase the derived roadmap is evaluated and projects ensuring progression along the chosen trajectory is undertaken. The technology roadmap is also frequently updated in response to changing factors in the environment.

It is mentioned that the level of buy-in maintained throughout the mapping process, determines the level of effort required during this phase. High levels of buy-in will require little conscious effort to be spent on follow-up activities, since role players will engage spontaneously. Low levels of buy-in requires the sponsor to continue to play a more active role in ensuring that the roadmap remains relevant.

The following steps are recommended:

- validation of the roadmap (The validation process is aimed at ensuring that the selected technology-business trajectory is optimal, that the trajectory is achievable as indicated and that no oversights have occurred. It also involves communication of the roadmap to the rest of the company at the relevant level of detail.)
- implementation (The chosen trajectory should now be deconstructed into one or more manageable programs (sets of projects). The progress of these programs are monitored and used to update the roadmap)
- continuous updating (Ideally, roadmaps should be updated at intervals frequent enough to ensure their relevance and accuracy. This involves reiteration though all the above roadmap steps.)

7.2 The EIRMA Working Group process

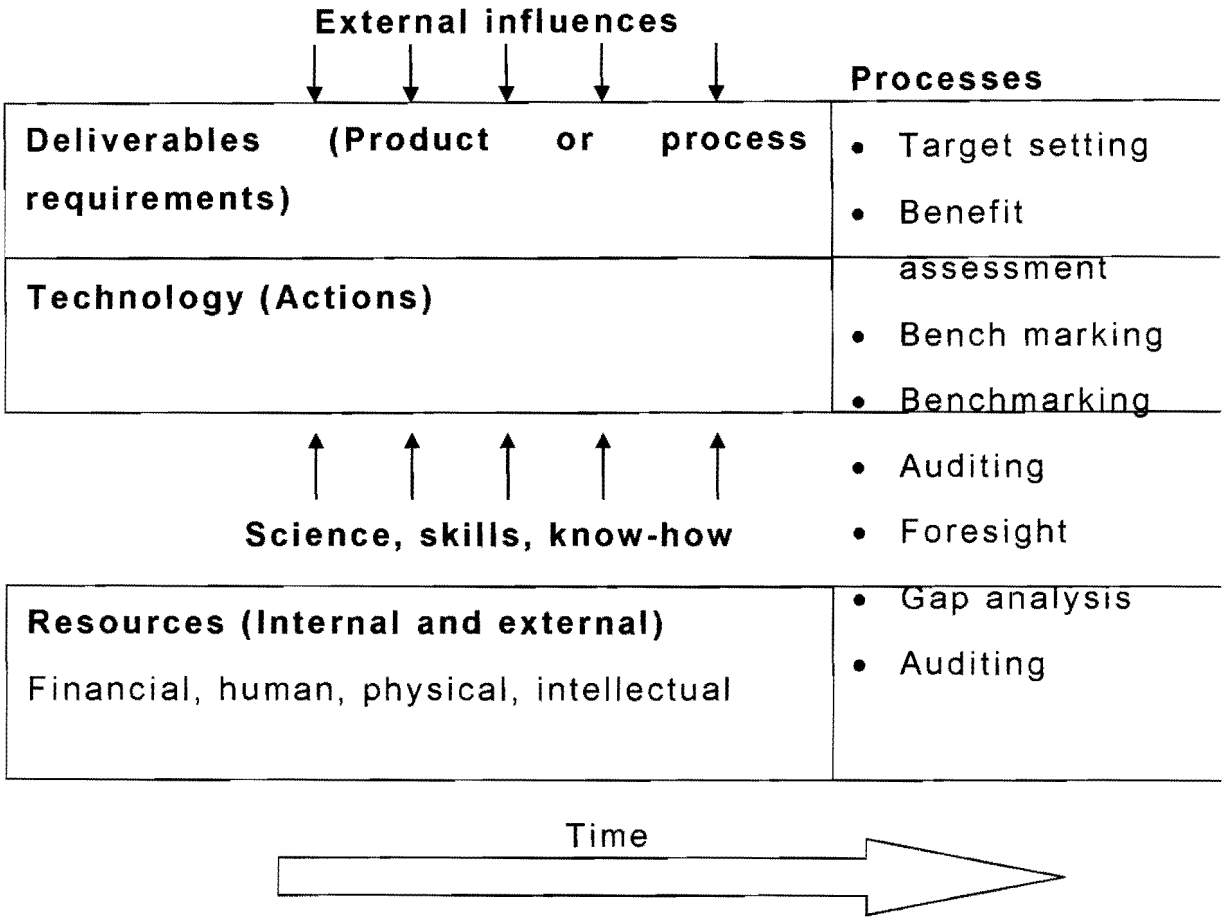
The generic technology roadmap

The characteristic elements that a roadmap consists of are (EIRMA Working Group):

- Time (Since a technology roadmap describes the current, desired future and intermediate stages; anticipation and foresight is an important aspect associated with roadmap) Historical trajectories might also be included.
- Deliverables (These are often desired performance target trajectories over time for products or processes. It includes a sense of the benefits derived from meeting these targets, together with a strong view on the impact of external influences, which are used to obtain the required deliverables; these elements are often supported by a hierarchy of sub-roadmaps depicting how these elements are obtained and developed; these may include technological capabilities not currently possessed by the firm.)
- skills and science (These are needed to develop or sustain the required technologies)
- resources (This includes internal resources such as financial, human, intellectual and physical assets as well as external resource requirements)

A diagrammatical representation of the generic technology roadmap is given in figure 18.

Figure 18 ***Diagrammatical representation of the generic technology roadmap***



The EIRMA Working Group on technology roadmaps has outlined an example of a roadmapping procedure.

1. Pre-project phase

Technology roadmaps are often constructed in response to the detection of a knowledge gap concerning the integration and interrelationship between different technologies, as well as between technology and business goals. Once this impetus is provided, the roadmapping processes is initiated through the following steps:

- Definition of the scope of the technology roadmap (The scope delineates the area of interest that should balance width / depth to ensure relevancy and accuracy with narrowness / shallowness to ensure manageability.)
- Definition of the product / technology level (In ensuring that the technology roadmapping process is restricted to the area of interest, it is important to define the technology application level as either system, product (or process) group, product (or process), module, component or material.)
- Appointment of the project owner (The project owner drives the roadmapping process. It is typically someone with a vested interest such as the relevant business owner.)
- Definition of the time scale of the technology roadmap (It is recommended that the time scale for the technology

roadmap is selected as intermediate between the short term operational time horison and the long term strategic time horison. Four to seven years are typical.)

- Definition of the task of the team (Additional orientation points and conditions, such as deadlines and resources, is made clear to the time during this phase.)
- Setting up the roadmapping team (The size and composition of the project team is strongly dependent on the nature of the specific technology roadmap and the nature of the company. The internal personnel used is selected to adequately represent the organisational structure, including all relevant functional areas, such as marketing, manufacturing, research and development and financial departments. If the roadmap incorporates areas of expertise not available within the company, external experts should be contracted.) It is recommended that the facilitator is both experienced and neutral.

2. Preliminary plan for the roadmapping project

The initial project plan is now fleshed out by the complete project team. The following issues should be addressed:

Technology assessment to determine which technologies would be required at different points in time

- expected trends
- market evolution over the medium to long term
- product (or process) evolution
- changes in consumer habits
- technology trends
- environmental constraints on the firm

- analysis of strengths, weaknesses, opportunities and threats
- relevant competitor analysis

3. Processing of the inputs

The primary source of information inputs is presentations by the various functional departments on potential scenarios for the business. Typically, each department concentrates on a specific information level of the roadmap (external requirements, deliverables, technology, science / skills / know-how or resources).

The assembled information is surveyed to identify the key driving factors for the technology roadmap under consideration. Typical drivers are: customer needs, product cost, technological feasibility, legislation or environmental stressors.

With the drivers known, various options that satisfy these critical requirements are explored. These options can be represented on a first-pass technology roadmap that shows all possible business-technology trajectories.

The importance of open and accurate communication during this stage is stressed. The multidisciplinary, multilevel nature of the team could complicate the process due to problems with sharing sensitive information or different factions within the group working at cross purposes to promote their own agenda.

4. Compilation of this information into a working document

This phase focuses on the selection of promising and appropriate technology-business trajectories that would meet the critical requirements.

The potential trajectories are ranked and risk assessed. The methods for ranking and assessing risks of trajectories is strongly company dependent and will be similar to those used to select research and development programs.

The selected trajectories should be evaluated for clashes with other technology roadmaps or strategic plans. All functional departments that could be impacted on by the implementation of the proposed technology roadmap should be consulted.

In constructing a technology-business trajectory, either of two approaches (or a combination of both) is used. In the first, a future target is fixed and the intercept trajectory is constructed backwards to the current point in time. This is known as the backward or top-down approach and is typically followed by a market driven company.

In the second method, a current technology is fixed as the starting point and the trajectory is constructed forward in time to determine favourable future targets. This is known as the forward or bottom-up approach and is typically used by technology driven companies.

It is possible to use a combination of these two methods.

5. Checking, consulting and communication planning

Validating and communication of the technology roadmap is now undertaken. Everyone affected by the technology roadmap should understand its implications, ranging from the operational departments that would be involved in implementation to the strategic management level. Criticisms arising at this point should serve as feedback for reviewing the technology roadmap.

6. Formulation of a decision document

The technology roadmap does not serve as a decision document. Addressing implementation issues and developing project plans are now required.

7. Updating

This step is devoted to defining a process for maintaining and updating the roadmap continuously. This process should be integrated into the regular business planning cycle.

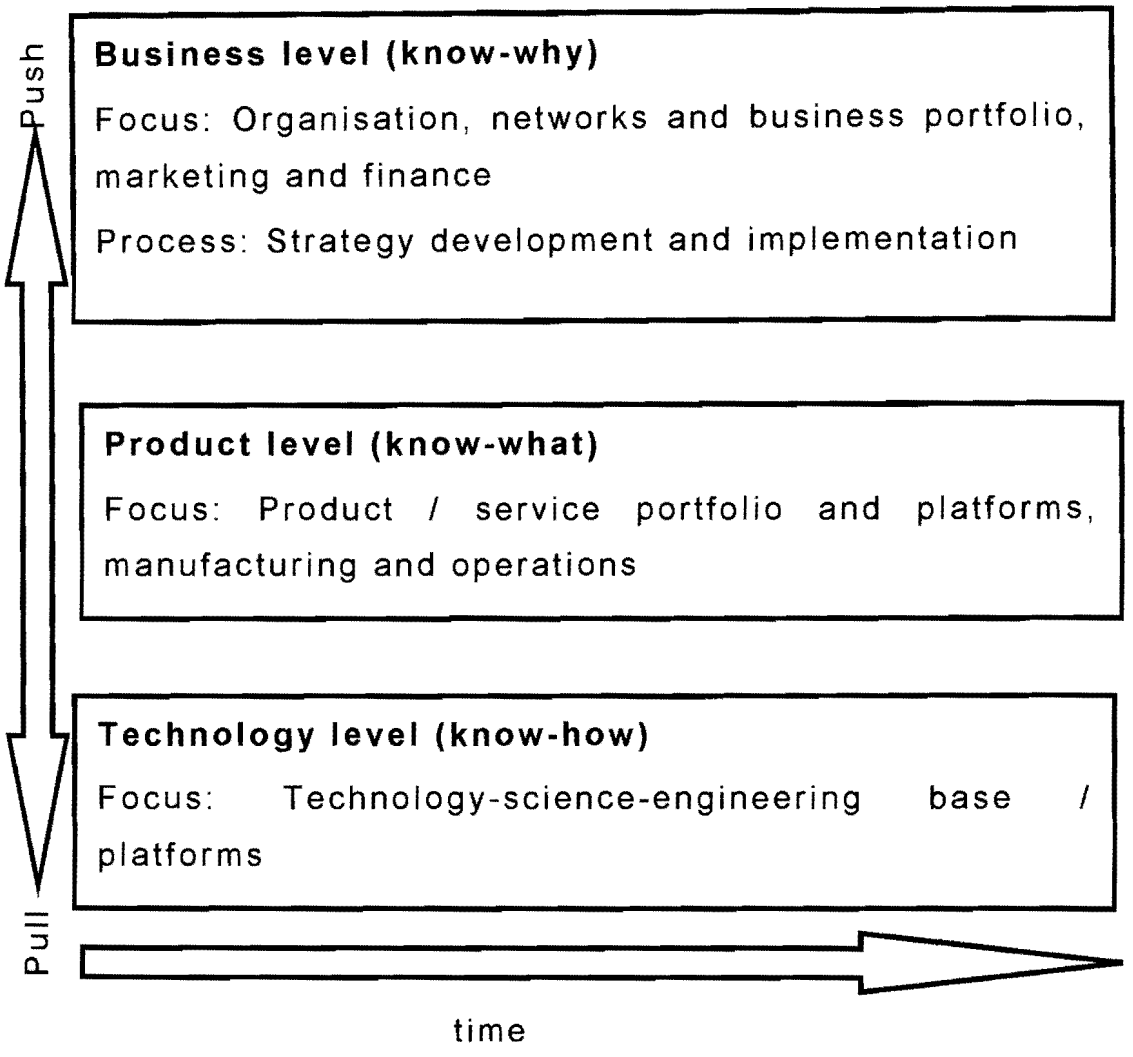
7.3 Fast-start technology roadmapping process

This process, developed at Cambridge University, is aimed at the rapid initiation of technology roadmapping. It is specifically developed for use in manufacturing but is flexible and could conceivably be adapted to suit other contexts (Phaal et al. 1999).

The process views technology as an important business resource which, together with other resources and activities, needs to be aligned in order to create a sustainable competitive advantage.

This process integrates the external view of competitive advantage that focuses on market opportunities and threats with the internal view that focuses on firm strengths and weaknesses. The external view represents the principle of market pull while the internal view represents that of technology push. These two principles are reconciled in a technology roadmap which integrates three different levels of knowledge, namely business level (know-why), product level (know-what) and technology level (know-how). These levels are depicted in figure 12 (Source: Phaal et al., 1999). The framework facilitates knowledge flow between the different levels.

Figure 12 ***The different dimensions across which knowledge flows***



In applying the framework, Phaal et al. (1999) identified the following major practical problems:

- selling the concept
- initiating the technology roadmap process
- defining the scope of the technology roadmap process
- integrating the technology roadmap into existing business processes and systems
- maintaining the technology roadmap processes on an ongoing basis

The process consists of five distinct phases, consisting of a preparatory phase followed by four separate workshops each focusing on a particular area.

The preparatory phase

This phase is aimed at creating the nurturing, dedicated environment in which the roadmap is developed. It consists of some of the following activities:

- Identification of appropriate participants
- Required resources and scheduling of workshops
- Identification of available information
- Definition of the unit of analysis
- Articulation of the company objectives for the process

Workshop A Business drivers

This workshop is primarily concerned with establishing a prioritised set of business drivers, reflecting both external and internal elements.

Workshop B Product features vs. business drivers

The purpose of this workshop is to determine a set of conceptual product features that satisfy the business drivers identified in the previous workshop.

Workshop C Technological solutions

This workshop aims at selecting potential technological solutions which would assist in achieving the required product features as determined in Workshop B.

Workshop D Roadmapping

The purpose of this workshop is the integration of the different knowledge levels addressed in the previous three workshops.

7.4 The Motorola roadmapping process

Motorola is a technology based company that utilises science to respond to customers' needs (i.e. needs driven). Technology roadmaps are perceived as facilitating the process of technology planning and management within a complex environment.

Two types of roadmaps are commonly used, that being emerging technology and product roadmaps. The process utilised to construct the product roadmaps are described below (Willyard and McClees, 1987)

Step 1 Description of the business

The business is described in terms of the elements discussed below.

- *Business mission* The business mission statement is an expression of that which the business must achieve to grow and improve. It supports this by stating cherished strengths which is available to business in pursuing this mission.
- *Strategies* A business strategy is seen as a set of decision over time on resource application in the pursuit of achieving idiosyncratic competences which eventually adds value to customers. With regards to product strategy in particular, the areas of performance, service and cost must all be addressed.
- *Market share* This information typically centres on the current market share, the position of competitors, as well rates of change in market share.
- *Sales history and forecast* This section specifically acknowledges path dependence by utilising historical data to forecast future sales. Marketing strategies and other known competitive forces are incorporated in the forecast.
- *Product life cycle curves* Whereas companies aim for continuous growth, the products underpinning this are subject to life cycle curves which moves from product introduction to obsolescence. These well-established curves are used determine the timing of projects aimed at replacing the old products.

- *Product plan* This plan is the synthesis of several predictive tools covering all aspects of development timeline, technical specifications, marketing and costing
- *Experience curve* Based on their observations, the Boston Consulting group theorised the continuous decline in product cost as a percentage function of cumulative experience. This principle is used to predict future product costs and pricing.
- *Competition* Analysis of the companies current and expected future competitive position is instrumental in technology selection and portfolio management.

Step 2 Technology forecasting

Building an element of accurate technology forecasting into a product roadmap, provides managers with an invaluable tool in gaining insight into the future. Due to the prominence that this feature of roadmaps enjoy, the importance of employing a rigorous set of tools improve accuracy, is strongly emphasised.

Step 3 Roadmap Matrix

This matrix shows the product plan and technology forecast (one axis) as a function of time (second axis). Its main benefit is seen as that powerfully communicating indicating product direction and timing.

Step 4 Quality

Since Motorola is a discrete product manufacturer this step places specific emphasis on the impact that new technology is expected to have on product quality. The concept of quality-in-design is addressed.

Step 5 Resource allocation

Based on the roadmap matrix, this step specifies resource requirements as a function of time. Resource requirements are stated both in terms of quantity and quality, for instance:

- amount of people and level of skills required
- amount and type of working space required
- type and amount of funding required
- potential level and type of external skills required

Step 6 Patent portfolio

Being a technology company, Motorola places strong emphasis on its patent portfolio. It indicates patent information on all technological components on its roadmaps, as well as indicating those areas where its competitors have established proprietary positions.

Step 7 Product descriptions and status reports

These documents regularly compare actual program performance against roadmap expectations. It thus creates a feedback loop which managers utilise for control.

Step 8 Minority report

This step is aimed at drawing attention to technologies which are currently marginalised in an attempt at preventing important technology issues being overlooked.