De Wet G (1992), Technology Space Maps for Technology Management and Audits, in Management of Technology III, Tarek Khalil & Bulent A Bayrakter, editors, Miami, Florida, February 1992, Industrial Engineering & Management Press, Norcross, Georgia, pp 1235 - 1243.

TECHNOLOGY SPACE MAPS FOR TECHNOLOGY MANAGEMENT AND AUDITS

GIDEON DE WET
FACULTY OF ENGINEERING
UNIVERSITY OF PRETORIA
PRETORIA 0002 REPUBLIC OF SOUTH AFRICA

ABSTRACT

A technology space map consisting of two dimensions such as system life cycle and system hierarchy has been found to provide a practical means for looking at corporate business activities, as well as at a more detailed level to assess technological capabilities and gaps for achieving strategic goals. Addition of further dimensions such as "discipline" and "time" allows contours for future development to be constructed, for technology strategy alternatives to be studied at executive level and for communication to corporate level. It complements Porter's model of the "center ring" of competition. At the detailed level, elements of technological capability could be described generically and/or specifically such that technologists could judge the scope and content of capabilities and levels of skill required to achieve objectives. This approach to technology auditing provides a simple translation to technology projects, and confidence to the practitioner, since the planning logic is traceable and within practical experience parameters.

INTRODUCTION

Communication across the interface between corporate and executive management in organisations must occur in a language that is both clear and acceptable to corporate managers if technology is to receive its proper share of attention during corporate strategy formulation. Unless this happens, opportunities for technology-based improvement and/or survival will be lost. [Van Wyk in Khalil (1988), Wolff (1990)]

While concepts such as a Technology Balance Sheet (BS) and a Technology Income Statement (TIS) have been suggested by De Wet (1990) to allow the use of terms familiar to corporate (financial) managers, additional models for presenting complex technical concepts in a simple manner could enhance this communication even further.

Technology space maps, presented in this paper, are essentially a form of shorthand used by technology managers that is easily understood by non-technologists for the discussion of strategic issues.

Developed into some further detail, the same maps allow the auditing of the present status of the technological capabilities in an organisation and provides a basis from which experienced technologists can determine the scope and content of technology development and/or -transfer projects to achieve desired future capabilities.

THE DIMENSIONS OF TECHNOLOGY SPACE

Capability as Technology

Van Wyk (1988) defines technology as "created capability", ie technology is capability created by man in contrast to natural phenomena and resources. Burgelman and Rosenbloom (1988) suggest that "it is useful to examine the technological strategy of a firm through the lenses of the underlying capabilities and the resultant modes of performance". Technology space maps are based on a similar perspective, where the term capability is used in its comprehensive sense, without an a priori definition. The implicit definition should emerge as the concept is developed.

Capability and System Life Cycle

System engineers have various ways of subdividing the system life cycle into phases. One typical sequence is given in Figure 1:

RESEARCH	DESIGN	DEVELOPMENT	PRODUCTION	SUPPORT	USE

Figure 1: System life cycle phases

Looking at the life cycle from a capability perspective, it is evident that the capability to do research on a particular system is not the same as that required to manufacture/produce that system. Similarly, the capability to design it would be different to that of system maintenance.

One way of classifying capabilities could therefore be to arrange them according to applicability to various phases in the life cycle.

Capability and system hierarchy

The notion of system hierarchy provides a second system perspective. Typical levels in the system hierarchy could be as shown in Figure 2:

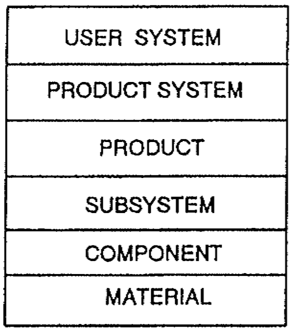

Figure 2: System hierarchy levels

As in the case of the life cycle, it is evident that the capabilities to design a product system such as a type of vehicle together with its integrated logistic system, would be different to those necessary to design the engine (ie sub-system), or the suspension elements (ie components). Similar arguments could be pursued up and down the system hierarchy for any phase in the life cycle.

Another dimension for the classification of capabilities could therefore be to arrange them according to applicability to various levels in the system hierarchy.

The S-L-H-Map

By combining system life cycle phases and the levels of hierarchy into a two-dimensional morphology, the S-L-H-Map is obtained, as in Figure 3:

	RESEARCH	DESIGN	DEVELOP	PRODUCE	MAINTAIN	USE
USER SYSTEM						
PROD. SYSTEM						
PRODUCT						
SUBSYSTEM						
COMPONENT						
MATERIAL						

Figure 3: The S-L-H-Map

Other dimensions for technology space

While the S-L-H-Map may be the most frequently used representation of technology space, several other dimensions could be considered, such as

* Engineering disciplines
* Application areas
* Market segments
* Time
* Etc

Rather than to attempt to draw three-dimensional morphologies, it is usually simpler to use two-dimensional S-L-H-Maps. By labelling a particular map to indicate that it belongs to a certain category within a dimension, a third dimension could be accommodated, and by contouring along a variable in a further dimension, up to four dimensions could be represented. These aspects can be illustrated by means of the following example:

> Acme Airconditioners Inc. is a relatively small company that manufactures two types of airconditioners, namely window mounting selfcontained units and split systems where a single heat pump serves several separate units in neighbouring rooms. Acme purchase subassemblies and components from several suppliers. Their main activities are the design of the products, integration of the

subassemblies and adding components such as piping, wiring and control components.

The present business could be represented by the shaded area in Figure 4.

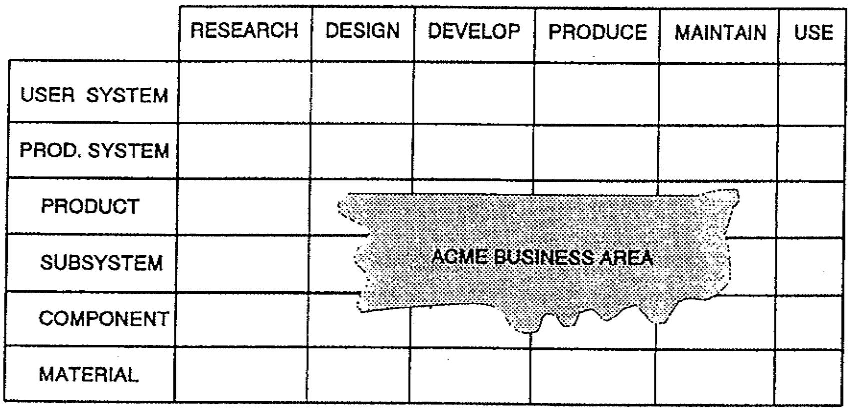

Figure 4: Acme Airconditioners capability contour

This area is obtained by the following line of reasoning:

- The S-H-L-Map could be labelled "Refrigerating Engineering" to indicate an engineering discipline, or it could be labelled "Airconditioning" to indicate an application area. Such identifications would of course be more appropriate at a next higher level of management, if Acme were one of the divisions of a larger, more diversified business.
- The products manufactured by Acme are classified as "products" in terms of system hierarchy level. However, since they buy in materials, components and subassemblies, they must have some capabilities to develop and manufacture subsystems and components.

- Apart from market research, done mainly by reading the relevant publications and listening to their customers, Acme do no formal research. They design according to "standard practice" for their product range. Their design capability consists of a drawing office, headed by a refrigeration engineer.

- Clients using Acme products expect Acme to render warranty servicing, but would rely on local repair and maintenance services for routine support.

Strategy formulation in technology space

Suppose that, based on market information, Acme should decide to enter the business of providing airconditioning systems for hospital operating theatres and micro-electronic circuit manufacturers. This represents a fundamental shift in the nature of the business and the concomitant capabilities that are required.
Figure 5 illustrates the results of the strategy formulated by Acme to achieve this transition, on the S-L-H-Map. The description of the strategy would read something like the following:

- Starting in 1992, we would have to add the capability of designing specialised subsystems for specific air quality requirements. Some simulation and testing facilities may be required to guide designs for custom systems.
- During 1993 this capability will be upgraded to support the design and development of the first products that would form the basis of our marketing effort to architects and project consultants.
- In 1994 our first new product systems will be manufactured and installed and maintenance rendered.

The information contained in Figure 5 allows the nature and content of new capabilities to be clearly communicated, including the scheduling of the various activities.

In terms of the strategic consideration of the five fundamental competitive forces in industry, proposed by Porter (1985), the S-L-H-Map provides a special perspective on suppliers and customers. This is indicated in Figure 6:

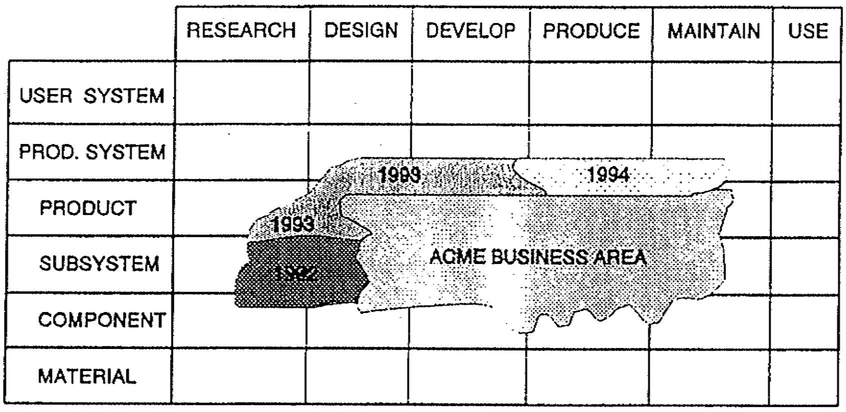

Figure 5: Acme strategy development contours

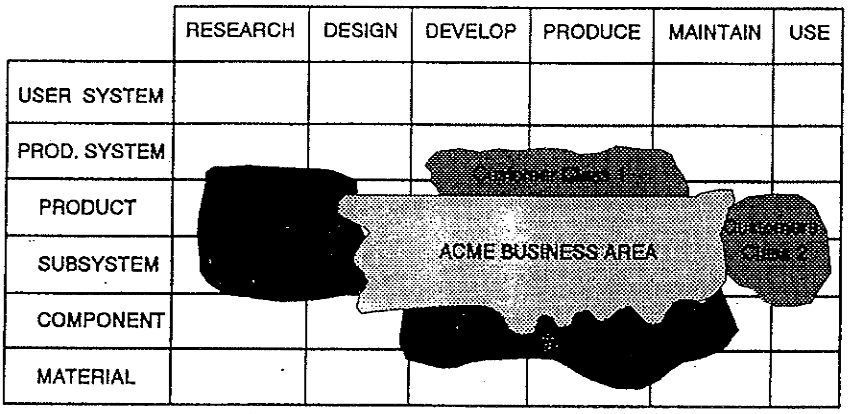

Figure 6: Acme customer & supplier analysis

Inspection of Figure 6 will suggest the difference between the respective classes of customers and suppliers. Customers class 1 would typically be industries using Acme products as building blocks in higher order systems. Buying in this market is often done by way of formal development and production specifications and contracts, by engineering personnel. Customers class 2 would normally be described as consumers, ie customers that buy predetermined product attributes and packaging. Marketing to these two classes of customers, as well as all the variations in between, has to be tailored accordingly.

While Acme would appear to be a class 1 customer to their class 2 suppliers, they would not be a typical consumer to their class 1 suppliers. As indicated on the map, these (class 1) suppliers may be either sources of information and knowledge that are contacted directly, or indirect sources such as publications and educational institutions. "Buying" from these suppliers, often referred to as technology transfer, is significantly different from buying as a consumer.

The S-L-H-Map therefore provides an additional perspective in competitive analysis. Using the concepts and terminology introduced by Porter, the Map could suggest strategies for the various classes of customer and supplier to become competitors in the relevant industry.

TECHNOLOGY AUDITING AND TECHNOLOGY SPACE MAPS

The auditing process

For the purpose of this discussion, a technology audit will be considered to consist of the process to determine the scope and depth of present capabilities, the scope and depth of capabilities to achieve goals implied by strategic objectives, as well as the scope and content of technology development/transfer activities to fill the gap(s) identified in the process.

Capabilities - a closer look

Up till now the contents of each block in the S-L-H-Map were described in general terms as "the capability to execute the work implied by a given life cycle phase of an artefact at a given level in the system hierarchy". While this may be adequate for strategic management purpose, it has to provide considerably more detail to be useful for technology auditing purposes.

The block that implies the capability to "DESIGN a PRODUCT" will be used as an example. While the elements of this capability may depend on the specific engineering discipline involved, certain generic knowledge, skills, tools and infrastructure may be identified, such as:

- design theory, knowledge, codes and practices
- specification writing and maintenance
- engineering management and contracting
- simulation, model building and testing
- program and product quality assurance and testing
- etc.

Such a list can be generated for each block on the Map, reflecting the detailed capabilities implied by the overall capability represented by the block. (This could be the first level of detail to define capability as technology.)

A convenient notation for expressing the relationship between the overall (block) capability and the more detailed elements, is shown in equation 1:

$$C_{L,H} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ \vdots \\ \vdots \\ \vdots \\ C_n \end{bmatrix} \qquad (1)$$

Where L = life cycle phase
H = level in system hierarchy
and C_1, $C_2 \ldots C_n$ are capabilities at the next level of detail

Levels of skill and time

Any single capability may be developed to a certain level of skill. The appropriate level of skill is determined by the actual function to be performed. Many levels of skill could be identified, depending on the complexity that the user requires, or finds useful. Experience in practical applications has shown that the following four levels are often adequate:

- Level 0 : no knowledge of subject
- Level 1 : knowledge of subject exists
- Level 2 : sufficient skill to buy service, product, etc
- Level 3 : sufficient skill to execute function independently

To illustrate the meaning of "appropriate levels" of skill it could be argued that an electronic designer at micro-chip level, needs no skill in the ergonomic design of television receivers. Similarly designers at product system level only need the skill to be able to purchase the subsystems they require, rather than to be able to design them. In general therefore it can be stated that not all capabilities need to exist at skill level 3. The manager of a particular set of resources should determine the required skill level profile for the capability elements within his particular functional group and try not to over- or underinvest in these levels.

When strategic changes like those depicted for Acme in Figure 5 are contemplated and scheduled for a company, new capabilities may have to be developed internally or obtained form external sources. Similarly, there should have to be adjustments to at least some of the levels of skill in existing capabilities and the target date(s) for achieving those levels would be pertinent information for management.

Expanding on the notation of equation 1, skill levels and target dates may be incorporated as indicated in equation 2:

$$C_{L,H} = \begin{bmatrix} C_1\ (s_1,t_1) \\ C_2\ (s_2,t_2) \\ C_3\ (s_3,t_3) \\ : \quad : \ : \\ : \quad : \ : \\ C_n\ (s_n,t_n) \end{bmatrix} \qquad (2)$$

Where $s_1, s_2, \ldots s_n$	denote skill levels, within the range 0, 1, 2, 3
and $t_1, t_2, \ldots t_n$	indicate the target dates in a convenient format, such as "1993"

Existing capabilities would be indicated by the present skill levels and a date in the past, to provide some information about the time that the capability, at the particular skill level, had been present in the firm. When the implications of strategic change have to be identified and quantified, an audit of present capabilities in each (relevant) lock of the Map has to be undertaken and listed as in equation (2). The next step is to identify new capabilities and the skill level for each one, changes in skill levels for existing capabilities, capabilities no longer required and, finally the target date for each of the changes. The results of this process could then be summarised as shown in Figure 7:

PRESENT CAPABILITIES	NEW CAPABILITIES	REMARKS
$C_1\ (s_1,t_1)$	$C_1\ (s_1,t_1)$	Existing capab.'s
$C_2\ (s_2,t_2)$	$C_2\ (s_2,t_2)$	& skills
$C_3\ (s_3,t_3)$	$\vdots$	maintained
$\vdots$	$C_1\ (s_1,t_1)$	
$\vdots$	....	....
$C_n\ (s_n,t_n)$	$C_k\ (s_k,t_k)$	Old capab.'s
	$C_1\ (s_1,t_1)$	new skills
	....	....
	$C_p\ (s_p,t_p)$	New capab.'s
	$C_q\ (s_q,t_q)$	New skills
	....	....
	$C_r\ (s_r,t_r)$	Redundant old capab.'s

Figure 7: Existing and new capabilities and skill levels

Once this information is available for each block affected by changes, it is possible to develop the content and schedule of technology projects to achieve the desired new capability profile. While it may be generally true that the scope and content of effort to "cross over" from an existing capability block on the Map to enter a new one is much higher than that of changing skill levels in existing capabilities, only experience can help in actually arriving at a reasonably accurate answer.

Similarly, if larger translations on the Map are indicated, various alternative routes may exist for achieving the goal. Only expert judgement can identify the most desirable trajectory. This can be illustrated by referring to Figure 5, where Acme decided to expand their capability for research and design at subsystem level, before tackling the product level. An alternative could have been to start on the development of the new product range first, identify the relevant research and design capability requirements to sustain this effort in future and then start to implement it in the most cost effective way.

CONCLUSION

This S-L-H-Map is a generic model delineating a space for all life cycle phases and all levels of system hierarchy. As such it reflects a system engineering perspective that is more relevant at the higher hierarchical levels than lower down. Materials and component suppliers develop (standard) "catalogue items". Here the life cycle could hardly include the phases of "maintain" and "use" since these suppliers seldom know whether their products are destined to be part of a new system or would serve as spare parts for an existing system. Similarly, at the levels of subsystems and some products, the life cycle is expanded for practical purposes to include phases such as "preliminary design", "detailed design" and "industrialisation". Such variations enhance rather than diminish the general utility of the concept.

A more detailed discussion on the practical application of the concept is beyond the scope of this paper, but it can be confirmed that it has been found to be of considerable value in a wide variety of technology management situations.

REFERENCES

Burgelman, R. A. and Rosenbloom, R. S. (1988) "Technology strategy: an evolutionary process perspective", Working paper, draft for Research on Technology Innovation, Management and Policy, JAI Press, Chapter 1.

De Wet, G. (1990) "Pathways for the management of technology", Proceedings, Inst for Future Research Conference, Somerset-West, October 1990.

Khalil, T. M. et al (ed) (1988) Technology Management Publication TM1, Geneva, Inderscience, pp. 93-99.

Porter, M. E. (1985) Competitive Advantage, New York, Free Press.

Van Wyk, R. J. (1988) "Management of Technology: new frameworks", Technovation, vol. 7, 1988, pp 341 - 351.

Wolff, m. F. (1990) "Managers at work: Michael F. Wolff interview William Matthew about "How to talk to your CEO", Research Technology Management, vol. 33, no. 1, pp. 11 - 13.

BIOGRAPHICAL SKETCH

Gideon de Wet holds the Chair for Engineering Management at the University of Pretoria. His career includes lecturing in electronic engineering, extensive experience in System Engineering, Program Management, Operations Research and Technology Management. He has been a consultant to major RSA industries and foreign companies. He holds a PhD in Electronic Engineering from the University of Stellenbosch.

-----//-----