THE MIGRATION OF A KNOWLEDGE ITEM THROUGH THE LIFE CYCLES OF TECHNOLOGY, PRODUCT DEVELOPMENT AND THE ENTERPRISE

G.D.P. Pretorius* and Prof. N. du Preez2
1Department of Industrial Engineering
University of Stellenbosch, South Africa
gert.pretorius@baesystems.com

ABSTRACT
This paper endeavours to define the migration of a knowledge item through the three different consecutive life cycles of technology, product development and that of the enterprise. As defined in a previous article about a universal knowledge framework, the knowledge item will be described using the knowledge cube structure. To further illustrate the migration route, four distinct, yet related examples will be investigated and the results discussed.

The examples are:
A. The idea that will later develop into a technology.
B. A technology that will be used in the design of a product.
C. A product that will be used in the development of an enterprise.
D. The end of life of the product system and the enterprise.

These examples are chosen so that it defines the beginning and end of each life cycle as well as the cross-over points between the different domains of technology, product and enterprise.

This article will conclude with some deductions regarding the knowledge migration through the Knowledge Migration Framework as defined by the combination of the specific life cycles (S-Curves) applicable to technology, product development as well as that of the enterprise.

* Corresponding Author
1 INTRODUCTION

This paper endeavours to investigate the migration of a knowledge item through the three different consecutive life cycles of technology, product development and that of the enterprise. As defined in a previous article on a universal knowledge framework, the knowledge item will be described using the knowledge cube structure developed before.

Figure 1: The Research Logic as applied to this article

The research logic as defined in Figure 1 requires the introduction of a number of models which are useful in its specific applicability but is required to provide research context. This article includes the virtual case studies A to D which will be fully described in this article but excludes the real case study as this research work still need to be performed.

This article will conclude with some deductions regarding the knowledge migration through Knowledge Migration Framework as defined by the combination of the specific life cycles (S-Curves) applicable to technology, product development as well as that of the enterprise.

2 THE KNOWLEDGE CUBE

From previous work of Pretorius and du Preez [1], it was concluded that a structural, a functional and a time element can be derived as common denominators or domains in the various knowledge models studied.

These domains were further developed to form part of a new framework called the Knowledge Cube. This Knowledge Cube can be used, not only to present knowledge or to assess technologies, but to be used as the core breakdown in the description of any knowledge artefact (cognitive or physical) to be used in a standardised way of defining attributes of such an artefact i.e. the knowledge itself.

The Knowledge Cube domains are further defined as follows:
2.1 The Structural Domain

The structural component of the framework consists out of the scoping of the artefact as well as its physical decomposition up to the level of description required.

This component can take many forms, like a system breakdown structure, a work breakdown structure, an information structure or even a physical structure like an atom that can be decomposed to a set of neutrons, protons and electrons. This element in essence defines the “what” component of the artefact’s attributes.

2.2 The Functional Domain

In both of the design methodology of Pahl and Beitz [2], and the axiomatic design of Suh [3], the function decomposition plays a key role, because this determines the functional structure.

This fundamental process definition is also confirmed by the Chen [4] in his mapping of the innovation production process. This component defines the “how” attributes of the artefact under review.

2.3 The Time Domain

Rozenfeld and Eversheim [5] argued that product development is essentially a knowledge creation process, therefore the knowledge management system links product development and knowledge evolution through the life cycle phases in context with the maturity state of the artefact.

The time or transformation, if time is not linear, is used to indicate the change process as well as the current or future state of the artefact’s attributes.

A typical description of the life cycle process and/or status of a product development at any given point in time can be part of such a description. This “when” component is also used to define age, maturity and any attribute related to the passing of time, or logic, in order to be able to fully define the attributes of an artefact.

2.4 The Combined View

The three elements of the knowledge cube framework is depicted in a three dimensional view. It is further postulated that these three domains are sufficient to cover all attributes of any artefact. (Big or small, simple or complex, real or abstract) It should therefore be possible to define both the idea of an idea as an artefact, as well as a very complex weapon system like an armoured combat vehicle with its associated support systems.
Figure 2: The Knowledge Cube defines the “What”, “When”, “How” Domains of any Knowledge Artefact’s attributes [1]

2.5 Knowledge Cube Value System

The value of knowledge implemented towards action in one context may be absolutely worthless in another. The operative meaning is that things that we perceive as valuable do not necessarily have intrinsic value. According to Ariely [6], artefacts are valuable, with the potential for value or perception making their value-ability come true within the organization and in its environment.

It is perhaps wise to divorce the term value from knowledge as it only gets realised in specific application profiles for a single knowledge item. Different knowledge items also realises different values when measured against the intended value system for its specific applications.

By considering the elements of the knowledge cube one can define the value to the user in two ways:

- The expected value (Required):
  This is a description of the value that a customer requires from a product during a typical acquisition process.
- The realised value (Available)
  This is the sets of values realised or claimed by different product candidates. The gap between the required values and the realised or claimed values in the different knowledge domains will be used by the customer to decide on the preferred candidate.
3 THE ENGINEERING CYCLES

3.1 The Basic Engineering Cycle

Brown [7] defines the basic design loop as follows:

*“Any design process comprises a basic sequence of tasks that are performed in various situations. Assuming that we have an initial concept about what should be achieved in the design process, the first step is to generate an initial design.”*
The next step is the simulation of the design at hand. If the simulation reveals some errors, then the design must be changed to overcome the problems. The redesigned version is again simulated to determine whether the errors have disappeared. This loop is repeated until the simulation indicates a successful design.”

Roozenburg and Eekels [8] defined the Basic Design Cycle with the following steps:

1. “Point of departure in product design is the function of the new product, i.e. the intended behaviour in the widest sense of the word
2. In the analysis phase the designer forms an idea of the problems around such a new product idea (the problem statement) and formulates the criteria that the solution should meet
3. The second step in the basic design cycle is the generation of a provisional design proposal. The word ‘synthesis’ means: the combining of separate things, ideas, etc., into a complete whole.
4. Simulation is a deductive sub process. Simulation is: forming an image of the behaviour and properties of the designed product by reasoning and/or testing models, preceding the actual manufacturing and use of the product.
5. Evaluation is establishing the ‘value’ or ‘quality’ of the provisional design.
6. Then follows the decision: continue (elaborate the design proposal) or try again (generate a better design proposal). Usually the first provisional design will not be bull’s eye and the designer will have to return to the synthesis step, to do better in a second, third or tenth time”

Figure 5: The Basic Design Cycle – Roozenburg and Eekels [8]

3.2 The Plan, Do, Check, Act (PDCA) Cycle

The Plan Do Check Act Four-step process are used in quality control and elsewhere as a simplified method for achieving improvements.
“These steps are: (1) Plan: determine what needs to be done, when, how, and by whom. (2) Do: carry out the plan, on a small-scale first. (3) Check: analyze the results of carrying out the plan. (4) Act: take appropriate steps to close the gap between planned and actual results. Named after its proposer, the US mathematician Dr. Walter Shewart (1891-1967). Also called Deming cycle, Deming wheel, or plan do check act (PDCA) cycle.”

![The Shewart Cycle](image)

Basic engineering design, in essence, is nothing other than taking an artefact’s current knowledge (problem, requirement, unwanted status), deciding how to go about changing it, actually changing the knowledge base, measuring the effectiveness of the change and repeating the process if the outcome was not acceptable. This is also commonly known as an Engineering or Design Cycle and is equally applicable to technologies, products and processes.

From the above it is clear that the PDCA Cycle is just another way of defining a Basic Engineering Cycle. This PDCA Cycle can therefore be used to indicate changes in the status of knowledge of an artefact during its life spanning from an idea right up to a full fledged system.

A knowledge artefact defined by the knowledge cube framework, therefore advances in its knowledge status by means of the continuous application of the PDCA Cycle.

4 THE LIFE CYCLES

4.1 The Generic S-Curve

S-curves are useful to contextualise maturity and strategic positioning of objects which maps growth of revenue or productivity against time.

According to Aït-El-Hadj [10], the lifecycle of technology can be considered in four phases namely:

a. The technology rise
b. Growth
c. Maturity
d. Saturation

Narayanan [11] states that the life cycle of innovations can be described using the s-curve. In the early stage of a particular innovation, growth is relatively slow as the new product establishes itself. At some point customers begin to demand and the revenue from the product increases more rapidly. New incremental innovations or changes to the product
allow growth to continue during this time. Towards the end of its life cycle, growth slows and may even begin to decline. In the later stages, no amount of new investment in that product will yield a normal rate of return. The s-curve is derived from half of a normal distribution curve.

With the stages combined this forms the classic S-Curve profile as defined below:

![Figure 7: The Life Cycle defined as an S-Curve [11]](image)

If we now apply the Basic Engineering Cycle as a means to propagate a knowledge item (Knowledge Cube) through the artefact’s lifecycle and we use the PDCA Cycle for demonstration purposes, it implies that we continuously repeat this cycle until we reach saturation in terms of knowledge potential and end of life for the specific artefact.

During this propagation the knowledge about the artefact is continuously being enriched by the application of the PDCA Cycle up to the point where more effort does no longer result in more knowledge. At this point saturation or maturity is reached.

![Figure 8: The Migration of a Knowledge Item through its Life Cycle](image)

In order to further investigate the migration of a knowledge item through the life cycle we need to investigate different applications of life cycles with regard to technology, product development as well as the life of an enterprise.

4.2 The Technology Life Cycle

From Wikipedia [12], the free encyclopaedia technology is defined as:

“The word technology refers to the making, modification, usage, and knowledge of tools, machines, techniques, crafts, systems, and methods of organization, in order to solve a problem, improve a preexisting solution to a problem, achieve a goal, handle an applied input/output relation or perform a specific function.”
The Merriam-Webster [13] dictionary defines technology in the following way:

“a: The practical application of knowledge especially in a particular area
b: A capability given by the practical application of knowledge”

Jayalath [14] defines the technology into a research and development and a vital life phase after which the technology is no longer useful. Again we can visualise that the development of a specific technology’s knowledge is through the application of the basic engineering or PDCA cycle.

A standard Technology Readiness Level Scale was initially developed by NASA and later adapted to the application in the acquisition process of the US Army through their Technology Program Management Model. [15]
4.3 The Product Life Cycle

The Business Dictionary [16] describes a product as:

“A good, idea, method, information, object or service created as a result of a process and serves a need or satisfies a want. It has a combination of tangible and intangible attributes (benefits, features, functions, uses) that a seller offers a buyer for purchase.”

As seen from the definition above no clear distinction can be drawn between the technology and the product life cycle start-up however in the interest of simplicity we will show two separate life cycles.

Figure 11: Model of reasoning by designers. Roozenburg and Eekels [8]

The Engineering Design Cycle and the Product Life Cycle (PLC) must not be confused with one another. The Engineering Design Cycle as defined above by Roozenburg and Eekels [8] is again the continuous process being used in order to forward or migrate the product’s knowledge attributes through its own life cycle (PLC) up to the point where more effort does not result in a more useful product i.e. the end of life condition.

The Product Life Cycle (PLC) as defined by Noyen [17] describes the whole life cycle of a product, from the first idea to the disposal of the product. The PLC can be divided in several phases as shown below:

Figure 12: The Product Life Cycle. Noyen [17]
BAE Systems [18] in their Engineering Life Cycle Handbook defines the Engineering Life Cycle of a Product or System as having five major phases as follows:

- Concept Creation Phase
- Development and Qualification Phase
- Manufacture Phase
- Support during Deployment Phase
- Disposal Phase

In addition 13 distinctly different design review gates have been identified in order to manage the success of the knowledge migration throughout the life cycle. These are depicted numerically in the diagram below:

![Image of Engineering Life Cycle diagram](image)

Figure 13: The Engineering Life Cycle of a Product or System. BAE Systems [18]

A whole variety of Product and Engineering Life Cycle Models exist in literature however the driving force of advancing the knowledge base of a specific product through its life is through the application of engineering effort in the form of repetitive engineering cycles.

### 4.4 The Enterprise Life Cycle

The Merriam-Webster dictionary [19] defines enterprise as follows:

- A project or undertaking that is especially difficult, complicated, or risky.
- Readiness to engage in daring or difficult action: initiative.
- A unit of economic organization or activity; especially: a business organization.

Of special interest to us is the Enterprise Life Cycle as defined by Noyen [17] as having six distinctive steps as depicted below:

![Image of Enterprise Life Cycle diagram](image)

Figure 14: The Enterprise Life Cycle. Noyen [17]

From the above it is clear that we must endeavour to re-create the enterprise before it reaches the end of life stage.
The classic enterprise life cycle also takes the form of an S curve as one half of the normal distribution and consists of the four basic phases of create, grow, operate and decline. The Next Institute [14] defines an optimal zone where conditions of energy, momentum, resources within the enterprise are most suited for the renewal of the enterprise. They further state that:

“The ability to recreate - to understand the Enterprise Life Cycle™ and renew in the optimum window - has become a fundamental requirement for creative and sustainable enterprise. If you’re leading an enterprise, there’s a conversation waiting.”

As was the case with the product life cycle, the enterprise life cycle also requires a method of continuous improvement. This is represented by the vast study field of Enterprise Engineering.

To take but one example, the US Department of the Treasury’s [21] Enterprise Life Cycle refers to an organisation’s approach for managing activities and making decisions during ongoing refreshment of business and technical practices to support its mission. This renewal process is defined in the figure below.
Figure 16: The Enterprise Life Cycle Activities inside the US Treasury Department [21]

Even in the most complex of Enterprise Engineering Models and Frameworks one can deduce the basic steps of planning, doing, checking and acting i.e. the PDCA Cycle as defined earlier.

The impetus for process knowledge enrichment during the Enterprise Life Cycle is again supplied by the churning of the PDCA Process.

4.5 Knowledge Migration Framework

If we now combine all of the above into the three consecutive life cycles of technology, product development and the enterprise and we define the common process that drives the change in the knowledge artefact throughout these cycles as the continuous use of the PDCA Cycle we can identify specific instances in the process that warrant further investigation.

Figure 17: Knowledge Migration Framework viewed as the Combined Life Cycles of Technology, Product and Enterprise.

We can now investigate the journey of an idea becoming reality in a proven technology into a product used by an enterprise and eventually phase out.
It is assumed that different life cycles will integrate in a logical way, but this will be tested during the assessment of the actual or real case studies and documented and feedback will be provided on in a subsequent (SAIIE or other) conference.

5 THE VIRTUAL CASE STUDIES

![Diagram showing the migration of a knowledge cube through the life cycles of Technology, Product, and Enterprise - The Knowledge Migration Framework.]

The following instances of the migration of a knowledge cube throughout the combined life cycles will be discussed:

A. The idea that will later develop into a technology.
B. A technology that will be used in the design of a product.
C. A product that will be used in the development of an enterprise.
D. The end of life of the product system and the enterprise.

The knowledge artefact that we are about to investigate starts with an idea for the active protection (counter blast) against blast mines built into an armoured vehicle which finds its way into a specific vehicle sold by the enterprise as a user system and eventually is supported in the customer environment during the mature stages of the enterprise life.

5.1 A - The Idea developed into a Technology

The structural domain of the idea knowledge cube can be defined as the scope, topic or description of the idea. In this case the idea to defeat a landmine blast by means of a counter explosion which forms a hydraulic wedge will clearly define the “what” component of the idea.

The knowledge cube’s functional domain where the main function is to survive; the first level breakdown then will be to protect. The further sub-functions will typically be to sense an explosion, to decide to react and to activate the counter explosion. This is the “how” domain.

The third knowledge cube domain is a description of the timeline where the initial blast takes 30 micro seconds to develop before sensing, the activation of the sensor within another 20 micro seconds and the activation of the counter blast within another 30 micro seconds giving the initial blast to raise about 500 mm before the counterblast is affected. This represents the “when” function. This 500 mm also represents the typical height of an armoured vehicle from the ground and is an obvious constraint for the idea to work.
If one considers two different applications of the idea for a normal commercial truck as well as for an armoured combat vehicle in order to assess the value of the idea, the following outcome can be envisaged.

Although the normal commercial truck is more than 500 mm high, it is not blast proof and the occupants will be worse off after the event and the application of the idea has therefore very little value.

In the instance of the armoured combat vehicle, the effect of such a system can be as much as 30% on the acceleration of the vehicle during a blast depending on other attributes of the vehicle (main cause of occupant’s injuries) and will carry real value for the soldiers.

This idea it must be developed into a functional system working together to demonstrate the required results for the idea to work. This will, in all cases, be required for the application of any idea. The increase in knowledge is obtained by means of the application of the basic engineering or design cycle. As we have seen before, this can be depicted by the PDCA Cycle. This increase in knowledge will allow the life cycle of technology to move forward from an idea to a successfully demonstrated concept, hence the notion of knowledge migration.

5.2 B - A Technology to be introduced into a Vehicle Concept

After the application of various engineering design cycles we eventually get to a proven technology at TRL 7 where it is ready to be incorporated into a specific vehicle concept.

The “what” domain is the scope of the technology under consideration as well as to decompose the technology to be able to define the underlying technologies required for successful operation of the main operation. In the specific case, we can scope the technology that will enable us to sense an explosion within 30 micro seconds from a distance of 500mm. This technology can be based on Electro Magnetic Pulse, Optic or Radar principles and must be able to perform in muddy, dusty or submerged conditions.

In the “how” domain we define all the sub functions that need to be performed. This may include the function to sensor, the packaging, the signal filters as well as amplifying the signal etc. Please note that through the application of the system engineering process as defined by Blanchard and Fabrycky [22], we will establish a relationship between the physical and functional domains when we perform a functional allocation to hardware in order to establish the required performance levels of each piece of hardware and the interfaces that exist between the elements.

The “when” domain defines the maturity state of the technology as well as the historic and future processes it still has to go through after integration into a product design. This will typically include the logic of first demonstration of principle, laboratory (engineering) test to refine the technology as well as formal qualification tests to demonstrate functionality in the field, reliability and safety to name but a few.

Similarly as in the previous case we can establish the value of the technology only when we apply it to a specific solution. In this case we use the design philosophy of the vehicle in order to evaluate the potential value of the chosen design above other considerations. This is a typical engineering trade-off study during development.

It does not take a lot of imagination to derive the fact that if we are busy integrating technology into a product design that this is done through the application of a design cycle. The knowledge about the product and its functionality, is enriched through the application of this cycle, in simplicity defined as the PDCA Cycle, and will lead to a better understanding of the product and its functions i.e. knowledge.
5.3 C - The Product used in an Enterprise

When we consider a product, in this case an armoured fighting vehicle, we need to define the vehicle as well as all the main elements of the vehicle i.e. the hull, the hydraulic system, the pneumatic system, the suspension, the driveline, the electrical system, internal fittings, the air conditioning system as well as the payload in mass, interface, centre of gravity to name only a few. This physical decomposition again is defined in the “what” domain. When we plan work on such a vehicle we also perform a work breakdown structure in line with the hardware breakdown structure. This can further be developed into a contract work breakdown structure if we do consider sub-contracting work.

In order for us to understand how it works, we need to define the different functions that such a vehicle can perform its mission or series of missions. This is classically broken down into mobility, fire power, C3I2, carrying of special payload and survivability. All of these functions are normally further decomposed to such a level that it can be allocated to a single piece of hardware, work breakdown element or sub contract. This is also performed using the system engineering process referred to above.

The typical project life cycle will be used to define the “when” domain. In a classic acquisition process performed under the military standards we will define concept, definition, full scale development, production, deployment and phase out components to be planned in the most concurrent way possible. The maturity level of the product design expressed on the TRL scale, is a typical knowledge attribute defined under the time domain.

When different armies procure an armoured combat vehicle they normally publish a weighted user value system that will be used to measure the level of acceptance. This value system will contain a financial element with regards to capital and operational costs, technical performance against the requirement specification, reliability, counter trade and other non-technical factors.

Again here it must be noted that the same product will score differently for different user value systems, thus, confirming that the artefact’s attributes are independent from the applied value system.

The development of a product into maturity is done through the application of an engineering cycle of the product. Throughout a development phase of the product we enhance the quality and the quantity of our product knowledge and by doing so we migrate the product knowledge towards maturity as defined before. Again it was shown that the PCDA Cycle is a good basic representative of an engineering cycle.

5.4 D - The End of Life Conditions of the Product System

The combination of various products and services into a system will, in this example, define the highest level of scope. The first level of breakdown is normally the products (vehicle, weapon system, communication equipment) and their associated support systems. As in the previous example the work breakdown structure as well as the contract breakdown structure is all part of the “what” domain. In this specific case we need to understand the role that the product is taking on with regard to the enterprise’s sales in its next business cycle to get a clear view as to the contribution the product represents.

We must have a clear understanding of the specific role this product has in the make-up of the user defense system to enable us to understand the alternative product strategies that can enhance the extension of life for the enterprise. In addition, we also need to marry the enterprise’s functional design with the future demands, this may lead to an enterprise re-design to focus on the after sales or support of the product as this will form a major part of the future business of the enterprise. This product and enterprise descriptive decomposition forms part of the “how” domain.
As seen from the end of life of the enterprise the specific contribution in the next business cycle to be obtained from the specific product depicts the “when” domain.

The true value of owning an enterprise is measured in the successful execution of the various contracts within the boundaries of affordability and efficiency. In other words, the sustained ability to make a profit in the next business cycle. As demonstrated, this is the result of a specific application of the artefact throughout its life, starting at an innovation through the successful incorporation into a product and ending in the strategic make-over of the enterprise in order to face the future business challenges.

This process is typically defined as the Enterprise Engineering Cycle and holds the process as the basis for renewal of knowledge or learning. This is the classic application of process renewal based on the PDCA Cycle.

5.5 General Discussion

As discussed in each example above the knowledge base will be enhanced through the application of the PDCA cycle or its equivalent in all the life cycles shown. Without the application of such a process the level of knowledge and understanding at that specific point in time will remain stagnant.

We can therefore conclude that the change agent that causes the knowledge artefact to migrate through the various life cycles is the application of the engineering process in various forms.

The complexity and maturity level of the knowledge item both grow with progress of the migration process. There is definitely a knowledge continuum in evidence through and between the various life cycles.

As the migration progresses and subsequently the complexity increases, more players get involved in the sharing of the knowledge of the artefact and this in turn causes potential knowledge gaps to open. This is especially the case where a new participant with limited exposure to the process joins the stakeholder groupings.

5.6 Conclusions

The integrated life cycle feeds on knowledge work in a continuum as discussed above. We can also conceive a pre-planned knowledge migration through the various life cycles of the Knowledge Migration Framework by taking pre-determined shortcuts in the processes, thereby defining a specific concurrent knowledge migration path. If we understand this migration process we will also be able to manage the inherent technical risk of such a plan.

The knowledge work continuum also evolves over time and, by definition, has its own life cycle as well. In order to shorten the time scale involved, as is required by the need for competitiveness one can utilise this knowledge continuum to evaluate and shorten the standard processes.

Some critical questions to be analysed during the proposed case study execution will be:

- The fit of best knowledge migration process (PCDA Cycle) to be followed in each case study in order to optimise the learning experience vs. time required.
- The best way to manage technical risk and how to apply the parallel risk abatement programs.
- Identifying the best points in the process to consolidate the knowledge base into a formal baseline of technical data so as to minimise both risk and time throughout the process.
- The integration required (or the jump) between S-Curves and how to best bridge this gap.

Should the framework deliver consistent results, the benefit of the research outcome will be:
The Knowledge Cube Principle can be applied to other areas of research in the domain of Knowledge Management.

A deeper understanding of the migration of a data item through the Knowledge Migration Framework may result in a method of depicting the level of concurrency in a specific process.

The overview of the models relative to the basic functions and lifecycle of an enterprise may lead to new understanding in the specific application of specific models highlighting the strong and weak areas of each one studied.

Additional research can be performed in the enterprise life cycle domain with regards to the Re-Correction Model as defined by Tan [23] may yield useful results. Further investigation of the framework surrounding the series of events when a knowledge item is presented to a customer in a successful way is also envisaged.

Figure 19: The Enterprise Life Cycle Re-Correction Model by TAN [23]
REFERENCES


[6] Ariely, Gil University of Westminster, UK and Interdisciplinary Center Herzliya, Israel


[18] BAE Systems, Lifecycle Management, The Handbook to the Engineering Lifecycle, HB05/01, This is an unpublished work created in 2005 - 2011.


