APPLICATION OF KNOWLEDGE MAPPING TO THE ALUMINIUM INDUSTRY

Paul Evans and Ricky Ricks

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Our experiences in three different UK aluminium plants are reviewed here, under a scheme sponsored by the Aluminium Federation and the Non Ferrous Alliance.

Technology Strategy Consultants

Innovation Centre, Warwick Technology Park, Gallows Hill, Warwick CV34 6UW, UK

Telephone: + 44 (0)1926 623 147/155 Fax: +44 (0)1926 623001 enquiries@tecstrat.com www.tecstrat.com

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Introduction

In the continuous struggle to improve its competitive position, most Western manufacturing industry has had to cut its cost base ruthlessly. The resultant de-layering has frequently resulted in a dilution of the knowledge-base and technical skills at the operational level. Where there was once a technical department, there is often now a local technical manager, and a remote technology centre. Such centres frequently serve multiple locations, with the result that the needs of any one manufacturing site may only be partially met. Higher rates of staff turnover have also been partly responsible for this knowledge drain. Real expertise tends to be concentrated in fewer and fewer individuals: their departure from the company, for whatever reason, can leave a manufacturing operation very exposed. In spite of these trends, local manufacturing operations are increasingly expected to find solutions to their own technical problems, as central technology functions themselves are down-sized.

Knowledge Mapping is an approach designed to help manufacturing operations capture their distributed knowledge-base, and make it more readily available across a plant. Its origins lie in the Quality Function Deployment method, one of the many Japanese-developed management tools which were popularised in North America and Europe in the 80s and 90s.

Technology Strategy Consultants (***tsc***), has substantially developed this basic methodology, and embedded it in an easy to use web-based application. It must be stressed that Knowledge Mapping is more about the process a company goes through, and the resultant cultural change, rather than just being a clever piece of software. The Non-Ferrous Alliance (NFA), which is the trade body of the non-ferrous metals industry in the UK, were sufficiently intrigued by this process that they chose to subsidise the development of a series of Knowledge Maps (KMaps) in their member companies. The Aluminium Federation (Alfed) is by far the largest grouping within the NFA, and three of its members have participated in this scheme. The purpose of this article is to disseminate the experience gained in this exercise to the wider aluminium industry. Two other participants were from the titanium and lead industries, and their experiences will be reported elsewhere. For obvious reasons of commercial sensitivity, the actual content of the KMaps developed with the participants will not be divulged here: the intention is to describe the rationale behind these companies' participation, and the benefits they have experienced.

The KMap

The KMap is essentially a two-dimensional matrix, mapping the **stages** in the process stream against the **attributes** of the product. The stages are usually associated with major pieces of plant, or aspects of their operation. Attributes of the product can include those properties specified by the customer, in addition to defects for which a customer could reject a product, and internal quality control checks (which would not normally be seen by the customer).

Figure 1 shows an example KMap for an extrusion process: the details should not be taken too seriously, as this was prepared purely for the purposes of demonstrating the features of the KMap. The process stages run from preparing the *Charge make up* for a furnace, *Molten*

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metal processing and *DC casting* the billet, all the way through to *Anodising* the extrusion, and *Packing and shipping* it to the customer.

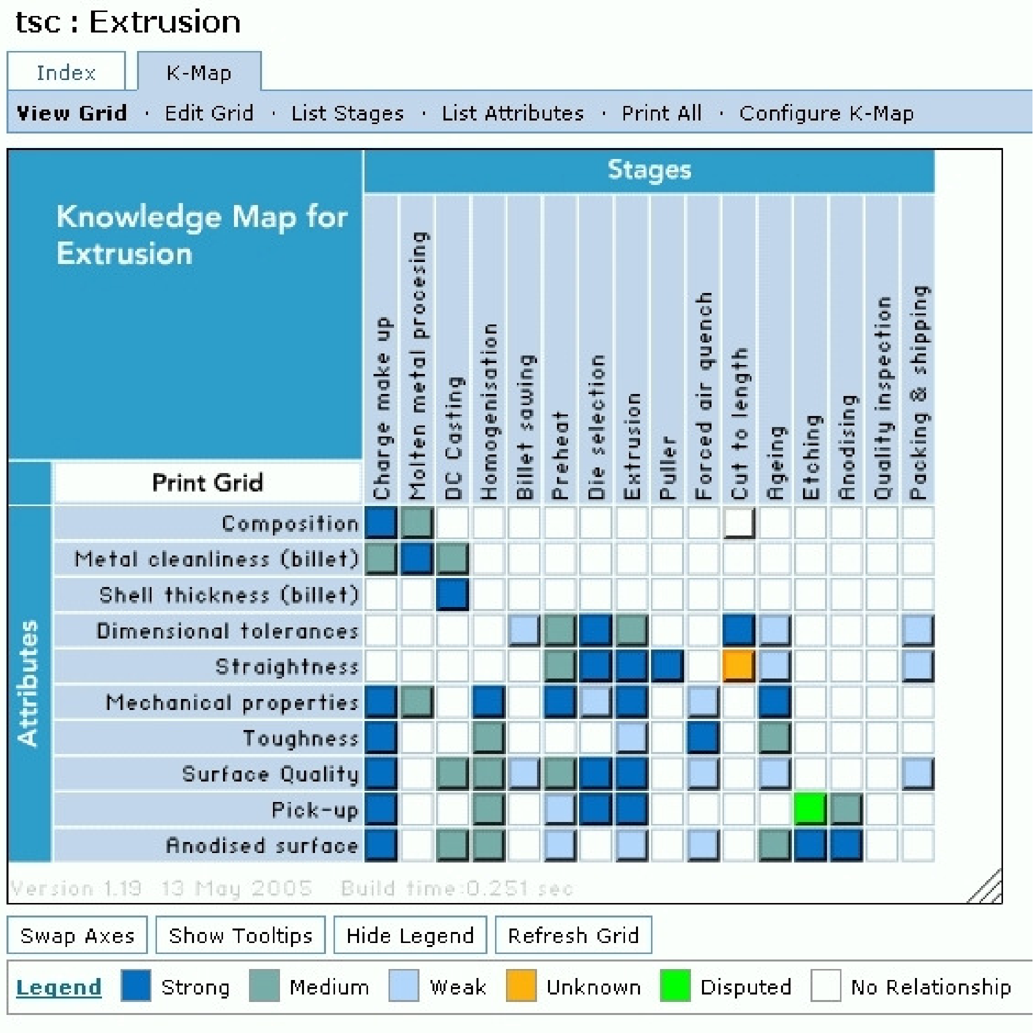


Figure 1: Example of a KMap for the manufacture of an extrusion

The attributes commonly tend to fall into a number of groups. Firstly there are internal quality control checks, such as *Metal cleanliness (billet)*, and *Shell thickness (billet)*, which the customer would not routinely see. Then there are geometrical properties, such as *Dimensional tolerances* and *Straightness*. Finally there are the bulk properties (e.g. *Mechanical properties* and *Toughness*) and the surface properties (e.g. *Surface Quality* and *Anodised Surface* appearance). Note also that “negative” attributes, or defects may also be included, such as *Pick-up*.

The map then shows where a particular process stage is known to influence a particular attribute: these relationships are indicated by the dark, medium and light blue squares. The colour indicates the strength of the relationship: this is determined qualitatively by comparing all those stages known to influence a specific attribute. Occasionally there are “unknown” relationships, or even “disputed” relationships, coloured orange and green on the map. These represent effects respectively about which there is either confusion or an absence of knowledge, or disagreement, often between the manufacturing and technical staff at the plant. The garish colours were chosen deliberately to encourage the team to resolve these issues quickly! To complete the picture, an empty square indicates there is no reason to expect a relationship, and no evidence for it, whilst a white square records a null result: an example is shown in Figure 1 for the effect of the *Cut to length* stage on the attribute *Composition.* This feature is useful for those cases where a plant once believed there was a relationship, went out of its way to prove it, only to find their designed experiment unambiguously showed no effect. The capture of such null results is important as it can avoid waste of resources when the same erroneous hypothesis resurfaces in a few years time, and everyone previously involved may have moved on.

The map shown in Figure 1 would provide an overview of the knowledge residing in our hypothetical extrusion company. This top level view itself has a number of practical uses. For example, if a plant is striving to reduce its costs, it might be tempted to change its preheat practice to lower its fuel bill. The KMap shows immediately which product attributes should be checked following a trial of a new preheat practice. Similarly, a product improvement project seeking to produce an extrusion with enhanced mechanical properties may target the extrusion stage itself as the means to achieve its objective. Again, the KMap highlights the other, equally important product attributes which must not be inadvertently harmed in achieving the target mechanical properties.

Going beyond the map of relationships, the KMap also then provides a repository for whatever knowledge and understanding exists in the company as to why a particular relationship exists. By clicking on either a stage, an attribute, or an intersection, a summary page is reached. For example, Figure 2 shows a summary page for the Extrusion stage.

In addition to a summary of this process stage, it is also seen that a number of **steps** within the stage have been identified. These represent a series of subsidiary activities within the overall process stage, which will subsequently be used to pinpoint which aspect of the stage is responsible for an interaction

Extrusion

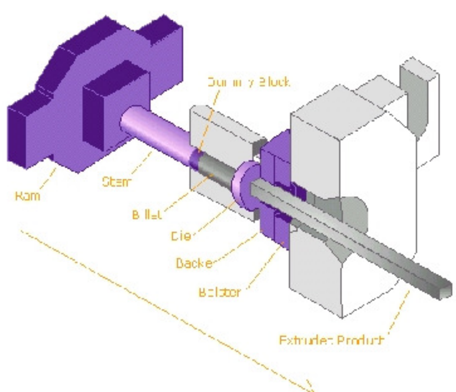
Extrusion

The extrusion process involves aluminium metal being forced through a die with a shaped opening. This is made possible by preheating the billet to 450-500°C and then applying a pressure of between 500 and 700 MPa. The heated and softened metal is forced against the container walls and the die by a hydraulic ram, the only exit is the geometric cross-section of the die opening, and the metal is squeezed out.

The preheat temperature and extrusion speed between them define the exit temperature, typically around 500°C. The process is operated to balance the requirements of the specified mechanical properties, a high quality surface finish and good productivity.

List Steps [-]
Set up parameters
Apply parting agent
Load billet
Burp cycle
Speed
Die temperature
Die shearing
Extrudate shearing

The Extrusion Press



The press supplies the force necessary to squeeze the billet through the extrusion die. It consists of:

- The container where the billet is put under pressure.
- The main cylinder with the ram for pushing the billet into the container and through the die.
- The front platen giving counter support to the die package.
- The main columns fixing the front platen and the cylinder together.

Figure 2: Example of Summary page for Extrusion (schematic press diagram from World Aluminium web-site)

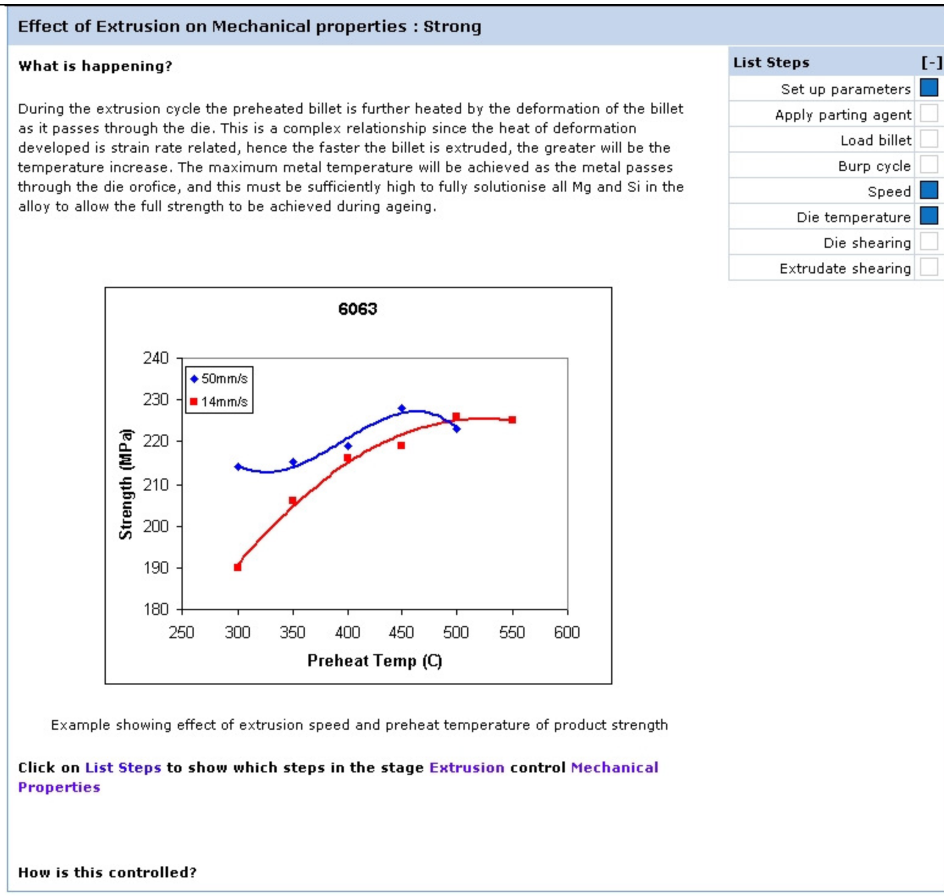


Figure 3: Example of a Summary page, describing the relationship between the Extrusion stage, and the attribute Mechanical properties

Figure 3 shows a summary page for a relationship: the effect of the Extrusion stage on the attribute Mechanical Properties. Such pages are constructed to contain a brief description, summarising the best understanding in the company explaining the cause of the effect, and to identify those steps within the process stage which are specifically responsible. Images may be included where this helps the explanation, although inclusion of extensive raw data is strongly discouraged. The intention is that this page provides a stand-alone summary of the cause and effect relationship, without swamping the reader with a plethora of supporting data. In fact the KMap can be extended to another layer below this summary page, where unlimited supporting "detail" can be assembled into a series of web pages if desired.

These examples from a fictitious KMap have been provided because the actual content developed with the participants in this scheme is obviously proprietary. In general a real KMap may comprise rather more stages and attributes than in this simple example: between twenty and forty stages and between twenty and thirty attributes would be typical. This is found to provide an optimum level of "granularity" in the KMap, such that the top level map is neither too condensed or simplified, nor too complex.

Ideally the KMap should be product-specific, or at least be based on a group of products which share similar properties and process routes. The map should also encompass all of the process stream residing within the company, since it highlights the way in which the product attributes are developed by a combination of events all the way down the stream. It is perfectly possible to develop a KMap for one part of the process stream, but the danger is that this may create a misleading view of the importance of the processes considered in the development of certain attributes (*i.e.* there may be far more important process stages up-stream or down-stream). It is also possible to develop a KMap for multiple products. The major caveat is that the resultant map tends to be dominated by the behaviour of the most demanding of those products considered. However, the differences between products can of course be brought out in the summary level information.

The KMap Event

The basic KMap is developed in about one week, facilitated by staff from ***tsc***. The process starts with a session where experienced staff from major parts of the process stream participate. For example, in a rolling operation, this would include a specialist from *e.g.* the remelt, the hot mill, the cold mill and the finishing operations. Their principal role is to develop a definitive listing of all the process stages. In addition the session includes staff able to determine a definitive list of product attributes. In the spirit of Six Sigma, this would ideally include representatives from the customer, although many companies are somewhat reluctant to expose their processes quite so openly. Consequently, representatives from the technical department, quality control and marketing are often used to develop this axis of the matrix. It is worth spending a little extra time at the start to get the matrix right, to avoid having to make too many modifications later on.

Subsequently, the facilitators meet with small groups from each operational area. These meetings should include the original representative from that area (*e.g.* the hot mill specialist in the example above), in addition to some experienced operators. This group will first define the key steps in the stages belonging to their area, and then work down each stage column, systematically addressing the question "does this stage affect a particular attribute". At this point, the existence of a relationship is recorded, but no attempt is made to assign a strength to the relationship. The responsible steps are also recorded, in addition to a brief description of their understanding as to why the effect is happening. The presence of technical specialists can be of assistance here, although not if it is found to limit the contributions from the operators. The operators' involvement is critical to ensure the K-Map captures what is actually happening on the shop floor, rather than what the technical specialists would like to believe is happening!

Each of these sub-meetings will last perhaps two or three hours. Allowing time in between meetings to "tidy up" the content (which has usually been thrown thick and fast at the facilitators!), it has usually been possible to work through all the process stages by the end of the week. Finally, the original team of experienced staff, who met at the beginning to define the matrix, are reassembled in order to normalise the KMap. This is a process which takes each attribute in turn, and seeks to categorise all those stages where a relationship has been identified as being strong, medium or weak. This is a qualitative ranking, based on the consensus of the whole team. Where the team can not agree, the relationship can be categorised as "unknown" or "disputed", which should encourage the team to undertake some controlled trials to confirm or otherwise the proposed relationships. The normalisation meeting itself lasts typically two or three hours, and generally provokes a lot of discussion.

tsc then spend a week or so editing the KMap, ensuring the content makes technical and grammatical sense. In this period, we communicate when necessary with the relevant contacts made in the first week, if clarifications or explanations are required. The KMap is then installed on the company's intranet, and launched to all the original participants, having defined appropriate access rights (*i.e.* defining editors and readers). Training is provided to the chosen editors, but the software is very intuitive, so this is normally very brief. There are a number of follow-on processes which a company can pursue in order to reap most benefit from its KMap, and these are discussed below in the section **After the Kmap**.

Technical Background

The K-Map is mounted on a company intranet server, and viewed and edited through a browser. The content of the KMap resides in a database (typically Access, but other databases can be used), and each web page is created on demand through an active server page (ASP). Access rights can be set up to create editors, who can change content, and readers, who can only view content.

The K-Map software used here was developed to our specification by Symbiosis (www.symbiosis.com), a software and training company based in Leamington Spa.

It should be stressed that the content of the KMap represents “authorised” information: it comprises the company’s best understanding of its process, and should not be changed at the whim of an individual. The team responsible for the KMap periodically review new developments, *e.g.* trials or customer complaints, and decide whether the content needs to be updated to reflect the advance of knowledge in the company. This is a very different process from using a search engine on the internet, where the onus is on the user to weigh up the often conflicting opinions found.

Case studies

Partly funded by the NFA, KMaps have been developed for a series of UK manufacturing operations. The case studies described below comprise:

- new product development at Bridgnorth Aluminium
- critical knowledge retention for casting expertise at the Alcoa plant in Kitt’s Green
- facilitating a knowledge-sharing culture in the manufacture of carbon anodes at Alcan’s smelter in Lynemouth

New product development

Bridgnorth Aluminium (UK) has historically focussed production on lithographic sheet and foil-stock products. Following its acquisition by Elval, Bridgnorth chose to expand its product portfolio to include a bright trim sheet product.

The new product had a number of demanding attributes, combining mechanical property targets with a general bright rolled surface. No chemical brightening is used, placing stringent demands on the control of the cold rolling process itself. A range of surface defects can be generated, which impair the quality of the bright rolled surface. Bridgnorth were in the midst of preliminary development trials when it was decided to participate in the NFA scheme.

"The KMap is an excellent tool for capturing new or existing product understanding and to ensure that resources challenged with product development first map the relationship between desired product attributes and manufacturing stages”, said Mr. Duncan Simpson, Bridgnorth plant manager. He went on to add: “This approach then builds knowledge and seeks to define where a relationship is strong, in order to manage the risk, or control product quality. We fully applied the tool to map the know-how of a small expert team tasked with developing a new product. We captured early knowledge from manufacturing trials and from the analysis of a complex range of product defects which appeared to have conflicting causes. In parallel, the product development also had to meet a challenging supply chain ramp up to full volume capability, with customer qualification. The KMap helped rationalise where we fully understood the process, and more importantly where our process knowledge was lacking.”

In summary, in Mr Simpson’s view: “The outcome was successful using this more structured, focussed approach to product development trials, and not only accelerated the overall process but captured all of the knowledge in a way that can be accessed easily and provides a sound platform to launch future improvements."

Bridgnorth have also developed a KMap for one of their other major products outside the NFA scheme.

Critical knowledge retention

The Alcoa plant in Kitts Green (UK) has a long history of supplying strong alloy plate to the aerospace industry. Strong alloys, based on the AA7XXX series, are notoriously difficult to cast, resulting in lower cast house recoveries when compared to locations casting simpler products. There is a well-known range of ingot defects, such as hot tearing, hot cracking, oxide patches, vertical folds, cold shuts, butt cracks *etc.*, all of which have the potential of causing a scrapped ingot. In the KMap parlance, a defect is just another type of product attribute, albeit an undesirable one!

In Kitts Green, the understanding and expertise in relating the occurrence of these defects to particular stages of the process stream was concentrated in a few key technical staff. In common with most manufacturing operations, a much wider range of operators also had extensive practical experience of defect occurrence, without the knowledge-base to understand the mechanism causing the defect.

The involvement of Kitts Green in the NFA scheme was precipitated by the imminent retirement of a highly experienced member of the technical team, and the desire to formally capture as much of his experience as possible. It was anticipated that the initial KMap, built in conjunction with the key technical staff and operators, would be further developed as a training tool, to help improve the understanding of the plant operators.

Figure 4: DC cast ingots

According to Dr. Alex Morris, Technical Manager of Kitts Green, "The KMap exercise itself was extremely useful. The system is up and running on our server, and we have been actively adding content, and links to other knowledge resources. Apart from capturing the knowledge of a key member of staff prior to his retirement, it also made us realise that written standard practices do not necessarily reflect what actually happens on the shop floor! By opening up the knowledge behind why certain actions are performed, it has helped us train operators to understand the importance of their tasks with respect to product quality, and get them to realise they are one link in a complex system. This system is an invaluable tool, helping in our efforts for continuous improvement."

Following the successful implementation of the DC casting KMap, Kitts Green has chosen to develop a KMap for the down stream operation of plate production, outside the NFA scheme.

Carbon anode manufacture: facilitation of knowledge-sharing

The Alcan smelter at Lynemouth comprises a power station, a carbon plant for pre-bake anode manufacture, a pot room and a DC casting plant. The carbon plant manufactures the consumable anodes used in the pot room. "Green" anodes are compacted from raw materials comprising ground coke, coal tar pitch and recycled spent anodes, before baking in pit furnaces. Anodes after baking are shown in Figure 5.

Figure 5: Carbon anodes after baking

As in many manufacturing operations, Lynemouth have recognised that much of their key "working" expertise resides in the minds of a few key individuals. In this context, "working" expertise, or tacit knowledge, is what a local plant relies on to solve most of its day-to-day problems. Alcan also operates central laboratories, where extensive theoretical expertise resides, but these resources tend to be focussed on more long term problems, rather than tackling the urgent issues arising unexpectedly in manufacturing.

Lynemouth has long had an informal knowledge-sharing culture, but it was recognised that the concentration of much of the technical expertise in a few individuals was a potential threat to the robustness of the manufacturing operation. Consequently Lynemouth were keen to participate in the NFA scheme to assess whether developing a KMap for carbon anode production would provide a more formal mechanism to foster the knowledge-sharing culture, and capture their key practical problem-solving experiences. Finding practical ways to avoid wheel-reinvention is a common theme emerging from many manufacturing operations, reflecting the down-side of de-layering, loss of technical skills, and general higher rates of staff turnover prevalent in modern manufacturing. The KMap is an ideal tool to help bridge the continuity gap. It was anticipated that a successful implementation could be followed by application in other areas of the plant.

Alcan as a global company has whole-heartedly embraced Six Sigma: a local Lynemouth Black Belt facilitated Lynemouth's involvement in the NFA scheme, and fully participated in the development of the anode KMap.

After the KMap

The KMap event itself can make a dramatic contribution to team-building within a plant, and encourage staff in one part of a manufacturing operation to realise the integrated nature of the whole process stream. However, maximum value is realised when the KMap becomes embedded in the normal operational routine of the plant. There are a number of ways this can be realised, although any one plant need not adopt them all.

Routine use. The KMap can be used routinely as part of any trouble-shooting exercise, or during improvement projects. It can be revisited in weekly production meetings: current customer complaints can be assessed against its content, to determine whether there is anything surprising about their occurrence, or whether they could have readily been prevented. In the case where new knowledge is developed in solving a complaint, it would be used to update the KMap. Further, in cases where the plant is trying to improve its product or processes, the KMap is used to ensure that the "improvements" don't inadvertently damage other attributes of the product demanded by the customer. In those plants which have adopted Lean Manufacturing, or Six Sigma (or Lean Six Sigma), the KMap should naturally be adopted by individuals tasked with running such projects (*e.g*. Green Belts or Black Belts).

SOPs. Very often during a KMap event it becomes apparent that there are discrepancies between what is actually happening on the shop floor and the Standard Operating Practices (SOPs) documented by the plant. Such SOPs were often prepared as part of an initiative to obtain a particular quality accreditation, sometimes by an individual who was not actually closely involved in the manufacturing operation. The discrepancies can have a number of causes. Occasionally parts of the SOPs were not actually correct in the first place. Alternatively, later equipment changes required new practices, or practices were subsequently deemed unsafe and eliminated (and the documentation was not updated). Less commonly, insufficient management focus was given to stress the importance of adherence to SOPs, leading to cultures where it was felt be permissible to "tinker" with the process (often with the best of intentions).

Having identified the problem during the KMap exercise, many plants choose to revisit their SOPs. They are generally encouraged to adopt a team-based approach to developing the new SOPs, preferably involving those who actually run the processes. The facility in the KMap to develop multiple detailed web pages below the stage summary can be used to permit multiple authors in the team to develop their SOPs in parallel. Alternatively, the SOPs can be developed by the team in *e.g*. .pdf format, then made accessible by a link from the KMap. This is the approach adopted by Bridgnorth Aluminium: hard copies of SOPs are not issued - the only way to access them as .pdf documents is through the KMap home page.

Technical Training. A KMap with extensive content can be used to revamp the training program in a plant. Too often in the past, training courses have relied exclusively on lectures (usually delivered by the central technology function). More modern methods stress the importance of discovery-, or problem-based learning. For example, a seminar should be backed up with a practical problem solving or workshop session, where the attendees get a chance to put into practice what they have in theory been absorbing. They can be taught team-based problem solving techniques, and shown how to use the KMap as a content-rich resource to help pull together the best information the company has relating to the specific problem. The structure of the KMap also positively encourages them to develop "working hypotheses" based on the available data, and then to design critical tests of those hypotheses. Of course this is nothing other than the scientific method, but in these days of rapid and easy data acquisition, it is becoming a dying art. Increasingly people never feel they have quite enough data or information to come to a conclusion.

Refocus R&D. The Research and Development function in any manufacturing operation can frequently become detached from the objectives of the operating units. Central laboratories have also been known to develop their own agenda. We should perhaps confess here that in considering our earlier careers, we would probably have to admit to having been part of organisations which behaved in just this way! This can clearly exasperate manufacturing plants, who don't feel they receive enough help tackling real, current technical challenges. The KMap shows where a company knows too little about its products and processes, and where it may know more than enough. As such it can help a manufacturing unit articulate and prioritise the areas in which it needs help. There is an unfortunate trend in corporate R&D functions to continue developing a specialisation far beyond that which the manufacturing operations actually require, or can even make use of: the KMap clearly identifies where such existing projects should be scaled back (or even stopped), and where new projects are required. It should be stressed that project needs defined following a KMap exercise would still need to checked against the company's strategic objectives (for example, it would not be apparent from the KMap that a company was planning to exit a particular market in the near term, rendering any such project irrelevant).

It should be recognised that by its very nature, the KMap brings focus to current issues and problems: projects arising will specifically address short to medium term issues, often termed continuous improvement. A very different approach is required to develop truly innovative products or processes.

Conclusions

Sponsored by the Non-Ferrous Alliance, a series of KMaps have been developed for manufacturing plants. Three of the participants are aluminium producers, and the experience gained during these three events is reported here.

The KMap event itself has been found to be very robust methodology, which provides immediate team-building benefits. In many cases, some of those involved had never had the opportunity to take a "helicopter" view of the overall manufacturing process stream, and often had only a limited appreciation of what attributes about the products were of particular value to the customer.

The combination of the KMap event, involving key players in the manufacturing plant including plant operators, and the KMap software itself, rapidly allows development of a sustainable knowledge resource, which can help alleviate the detrimental effects of knowledge draining from companies when key staff depart.

Perhaps most importantly, when the KMap becomes embedded in the everyday working practices of the plant, the move to a structured, knowledge-sharing culture can have a dramatic impact on the effectiveness of the operation. The KMap positively encourages a "joined-up thinking" approach, giving an integrated view of the manufacturing operation. Product and process development projects proceed in a systematic fashion, with less chance of accidentally damaging other product attributes outside the scope of the improvement project. The standard operating practices can also be embedded in the KMap, which becomes the portal to access all the key information about the manufacture of a product.

Finally, a live, content-rich KMap plays a significant role in other aspects of technology, such as revamping technical training courses along the lines of discovery-based learning, and bringing a lot more focus and rigour to the way in which the needs of the plant are articulated to define the R&D program of the company.