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**Barriers to Industrial Energy Efficiency**

**Structured Abstract:**

**Purpose (mandatory)**

Energy consumption is a significant contributor to the economic and environmental components of industrial sustainability and there is a significant body of knowledge emerging on the technical steps necessary to reduce that consumption. Achieving technical success requires organisational alignment, without which barriers to energy efficiency can be experienced. The purpose of this research is to capture organisational barriers that can inhibit energy reduction in manufacturing.

**Design/methodology/approach (mandatory)**

The research uses a theory building – theory testing cycle to propose and then verify existence of barriers to industrial energy efficiency. Literature review is used to build potential organisational barriers that can arise. The existence of barriers is then verified in industrial energy reduction projects using interview, observation and document analysis. Findings are validated by company staff.

**Findings (mandatory)**

From the literature barriers that can be related to energy reduction projects are uncovered. The generic and energy reduction specific barriers are confirmed and two new barriers are identified. A cognitive map linking the relationships between all the barriers is proposed.

**Research limitations/implications (if applicable)**

The research is built on detailed examination of a number of projects in a single company and work is needed to verify the findings in companies of different sizes and in different industrial sectors.

**Practical implications (if applicable)**

The list of barriers created can support industry in preparing for and undertaking energy efficiency projects. The cognitive map proposed will help industry and academia understand why removing current prominent barriers can lead to new barriers surfacing.

**Originality/value (mandatory)**

The novelty of this research is in both the creation of a list of organisational barriers for energy efficiency as well as identifying the relationships between them. The work brings generic change management barriers to enhance the specific energy reduction barriers together into a broader collation of barriers as well as uncovering new ones. The work proposes a cognitive map of industrial energy efficiency barriers to demonstrate their interrelationships.

**Keywords:** industrial sustainability, energy reduction, implementation barriers, organisational barriers

**Article Classification:** Research paper

1. **INTRODUCTION**

Reducing the energy consumption of manufacturing operations is becoming an attractive improvement opportunity for many organisations. For manufacturers which use energy intensive processes, reducing energy makes a lot of sense since it can form a large percentage of operating costs (e.g. 15-20% for steel manufacturing and 30% for aluminium – see Bauman et al. 2011). As the cost of energy continues to rise even manufacturers with a relatively low energy demand can see the advantage of reducing their cost of production by reducing energy.

As well as the immediate recurring cost benefits it is clear that using less energy will also have positive environmental benefits; most energy consumed in the UK comes from non-renewable sources (DUKES 2011) and thus a decrease in energy use means a decrease in the depletion of limited natural resources and a decrease in the subsequent production of greenhouse gases.

Financial security and environmental stewardship go hand-in-hand for companies seeking to operate in a *sustainable* way. Sustainable companies are those which seek to provide a benefit to society today without compromising their ability to continue to do so in the future (WCED 1987) and funding those activities is equally as important as protecting the environment in which they operate and the society to which they provide their goods or services. Saving energy both makes good financial sense and is clearly something which any sustainable company should seek to do.

All companies are facing financial pressures due to the increasing cost of energy (DUKES 2011) thus even for those companies which are not particularly environmentally conscious becoming more energy efficient is a good corporate strategy. However, in spite of the financial benefits of reducing operating costs through energy reduction many companies still operate in an energy inefficient way. This “energy efficiency gap” between the current wasteful state and an economically feasible more efficient future state has been explored in the literature (DeCanio 1993; Jaffe & Stavins 1994) and it is proposed that barriers must therefore exist preventing companies from becoming more energy efficient.

This research examines the organisational barriers to industrial energy efficiency through the use of case research. Given the absence of knowledge provided in available literature on energy related organisational barriers, the objective of this research is to identify organisational barriers to industrial energy efficiency.

This paper first presents a literature review on energy efficiency and then on the organisational barriers to change in companies. Next, the paper presents the collation of many barriers from the literature that are then verified multiple times in a case company. In the case studies section, three of the instances of the research are presented from the selected company from the UK aerospace sector. The barriers collated are confirmed and new barriers are uncovered. The discussion section then presents how during the work it was observed that there were interrelationships between the barriers and as a result a cognitive map of barriers is proposed. Finally conclusions present the contributions to theory and practice as well as opportunities for further work.

1. **APPROACH**

The research presented in this paper can be split into two distinct phases of theory building followed by theory testing.

The first part of the research identifies a possible list of barriers from a review of the change management literature through to specific literature in the field of energy efficiency. Interviews with people previously involved in manufacturing energy reduction activities were carried out to identify additional barriers (see Table 1). As a result of this first phase, a list of preliminary barriers to industrial energy efficiency was developed. This list of barriers is then verified in the second part of the research where three discrete case studies are presented from within the manufacturing organisation.

The company selected for the research was a large UK aerospace manufacturer. Selection of the company was based on convenience. It was accessible to the authors and the timing of the planned changes coincided with the research. Due to the size of the organisation and its relative inexperience in energy saving the company was able to support multiple cases for repetitive data collection whilst relatively few staff in the company were experienced in energy improvements. This inexperience meant the capture of the start of an improvement journey was possible. The tendency of the company to act independently of other companies reduced the influence of external factors on data collection.

The company employed many hundreds of staff across a large site with diverse production operations. Typical of a company of this size, staff were located in multiple separate clusters and collaborated across functional hierarchies and multiple shift patterns. Performance measurement systems were well established and whilst energy consumption was a concern the metric was held by facilities rather than shared with production. It had undertaken a small number of energy reduction projects to date and was about to embark on a significant programme of projects. An understanding of the value and process for energy reduction was established but it was recognised that barriers to the implementation of energy reduction existed.

The case studies highlight the barriers identified during the first phase of the research and demonstrate how and where they occur during the initiation and execution of energy reduction initiatives. Each case was tracked by means of interview, observation and document analysis. See Table 1 for a breakdown of the methods deployed.

|  |  |
| --- | --- |
| **Data collection methods and sources** | |
| Interview | Group. Semi-structured. Recorded by note taking. Actors from across business with representative job titles of: facilities manager, manufacturing engineer, improvement manager, manufacturing operations manager, operator (shop floor staff). |
| Observation | Recorded in journal. Observations taken from ad-hoc meetings, formal meetings, shop floor kaizen sessions |
| Document analysis | Proposal documents, reports, meeting minutes, technical memos, policy documents, organisational structures, data collection documents. |

Table 1: Data collection methods deployed

Analysis was undertaken by collating data using each data collection method. Each method collation therefore revealed the presence or not of a particular barrier. The barriers identified by each method were then collated into an overall view of the barriers perceived to be present for each project. Measuring the frequency of barriers being cited was not considered appropriate given the participants in the improvement projects were relatively low in number compared to the overall company population.

This provides a rich narrative from which conclusions can be drawn about the existence of barriers to industrial energy efficiency. The findings on barriers were then validated by company staff.

1. **IDENTIFYING BARRIERS**

Due to the historic low cost of energy, many manufacturing organisations have treated energy as ‘free issue’. However in the same way that material and time wastes were often overlooked until the introduction of new management practices in the second half of the twentieth century, (Deming 1982, Womack & Jones 1997) which helped to deliver a competitive advantage, the rise of the sustainability agenda is encouraging manufacturers to track down and eliminate their energy waste. The implementation of an energy reduction initiative is just like any other organisational change with many drivers for and barriers to that change. This research focuses on the organisational barriers to change, since by understanding the barriers it may be possible to design organisational interventions to overcome them.

Barriers from literature are presented first, progressing from generic barriers to change to specific barriers encountered in an energy context. Additionally some barriers are also presented from an interview conducted with a group of people involved in earlier improvement activities at the same manufacturing company (see Lunt & Levers 2010).

* 1. **Barriers in the Literature**

The management literature on organisational change discusses many methodological interventions for successfully implementing change (Kotter 1995, Argyris 1999, Illes & Sutherland 2001, Schein 2004). These approaches have been applied to many different situations across many different sectors, from consumer goods to healthcare, from corporate takeovers to the implementation of IT systems. However the approaches to organisational change have not been applied specifically targeting energy reduction initiatives. Perhaps the only such example is Senge (2010) who adapts his ‘five disciplines’ for organisational learning into an approach for sustainable change. Here he describes how systems thinking approaches can be applied in organisations wishing to act in a more sustainable way, borrowing many concepts from industrial ecology. Senge presents these approaches as tools – methods than can be applied individually rather than methodologies providing a step-by-step approach.

Although there is a lack of examples in the change management literature on how barriers were overcome, this literature offers a rich source of generic knowledge on the application of interventions to bring about positive organisation change. The language used is often positive describing the *correct* way of effecting change rather than discussing *barriers*. Kotter (1995) however does provide his drivers as barriers which can be seen in Table 2.

Focusing specifically on industry, there are many improvement methodologies familiar to manufacturers the goal of which is to seek to improve manufacturing efficiency. Examples include lean (Bicheno, 2004; Womack & Jones, 1997) as mentioned earlier, the goal of which is to minimise waste; six sigma (Pyzdek, 2003) the goal of which is to minimise variation; the theory of constraints (Goldratt & Cox, 1996) the goal of which is to maximise throughput along with many others. For manufacturers wishing to implement energy efficiency improvements, these approaches represent a starting point.

Lean in particular, with its emphasis on reducing waste, would seem appropriate for applying interventions focused on reducing energy consumption. Indeed, Kissock & Seryak (2004) and others (Kissock & Eger, 2008; Seryak & Epstein, 2006) have described how a side effect of implementing lean can be a reduction in energy, but there is little evidence from the literature that organisations are using approaches such as lean for targeting energy reduction as the primary focus.

As with the management literature, this literature too tends to focus on the successful application of the classic tools (Bicheno, 2004), but there is little useful knowledge that can be gleaned from success stories. Knowing what works for a particular company is only part of the story; it is also important to know the journey the company took to get there and how they overcame any barriers which inevitably appeared.

Turesky and Connell (2010) take a different approach and provide one of the few cases in literature which describes the failure of a lean initiative. They go on to show how the failings of the first attempt were overcome in a second attempt by identifying the barriers and designing appropriate interventions. From their description it is possible to highlight ten discrete barriers which occurred at different phases of implementation. These are shown in Table 2.

By narrowing the focus even further it is possible to find some authors who have looked specifically at barriers to energy reduction, most notably Sorrell et al. (2000). Sorrell et al. provide a taxonomy of fifteen barriers which have been used and validated by a number of subsequent authors (Rohdin & Thollander 2006; Thollander & Ottosson 2007; Palm 2009) and are shown in Table 2. These barriers are in part based on the work of previous authors looking at the economics of energy reduction (DeCanio 1993; Jaffe & Stavins 1994) and also show links with other authors (e.g. Weber 1997) who distinguish between behavioural (or individual) barriers and organisational barriers.

Table 2 provides a summary of all the barriers described in this section.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Kotter, 1995*** | | ***Turesky & Connell, 2010*** | | ***Sorrell et al., 2000*** | |
| 1 | No sense of urgency | 9 | No management support | 19 | Imperfect information |
| 2 | No powerful guiding coalition | 10 | Poor communication | 20 | Split incentives |
| 3 | Lack of vision | 11 | Inadequate training | 21 | Adverse selection |
| 4 | Undercommunicating the vision | 12 | Poor project selection | 22 | Principal-agent relationships |
| 5 | Not removing obstacles to the vision | 13 | Lack of engagement | 23 | Heterogeneity |
| 6 | Quick wins not planned or created | 14 | No desire to improve | 24 | Hidden costs |
| 7 | Declaring victory too soon | 15 | Managing resistance | 25 | Access to capital |
| 8 | Not anchoring change in culture | 16 | Unsuitable project team | 26 | Risk |
|  |  | 17 | Project incomplete | 27 | Bounded rationality |
|  |  | 18 | Lack of accountability | 28 | Form of information |
|  |  |  |  | 29 | Credibility & trust |
|  |  |  |  | 30 | Inertia |
|  |  |  |  | 31 | Values |
|  |  |  |  | 32 | Power |
|  |  |  |  | 33 | Culture |

**Table 2 – Barriers from the initial analysis**

Given that the number of barriers is fairly high and that they come from a range of sources it would make sense to group similar barriers from different sources together. However a review of the list of barriers will reveal that this is not possible without significantly altering the sense of each barrier and thus diminishing the value of the list. For example, one could argue that the barriers *no sense of urgency* (Kotter 1995) and *inertia* (Sorrell et al. 2000) are similar enough to be grouped together. However this would ignore the subtlety of meaning of each barrier, with *urgency* relating more to a barrier for people or organisations *in favour of* change and *inertia* relating to a reinforcing barrier for people or organisations *opposed to change*. Each author has a different perspective which is valuable in itself. For this reason no clustering of barriers will be performed and filtering will be based on observations made during the case studies.

* 1. **Individual Perception of Barriers**

In 2010 the researcher carried out a project on a process in a large aerospace manufacturing company the goal of which was to reduce as much energy as possible with minimum capital investment. The project lasted five months and resulted in savings of around 70% within the process perimeter. (See Lunt & Levers 2011.)

Although the project was deemed successful barriers were still encountered which meant that the process lasted longer than it could have and the savings were less than they could have been. In order to identify these barriers additional data collection was carried out through a semi-structured group interview with the project team. This team consisted of four people excluding the interviewer; two people from manufacturing operations (both shop floor), one from maintenance and one from facility management. The interview lasted approximately one hour and was centred around the two questions: “*What went well during the project*?” and, “*What went badly*?” which gave the interviewees freedom to express their opinions openly and extensively about the project performance. From the interview, eleven discrete barriers were identified, shown in Table 3. Although different barriers were raised by different people, all the interviewees agreed with the list of barriers produced.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Group Interview*** | | | | | |
| 34 | Inappropriate equipment | 38 | Lack of process knowledge | 42 | Fear of impacting product quality |
| 35 | Inadequate resourcing | 39 | Complexity of process | 43 | Fear of impacting health & safety |
| 36 | Unclear objectives | 40 | Reliance on third parties | 44 | Lack of engagement |
| 37 | Lack of structure | 41 | Inability to simulate |  |  |

**Table 3 – Barriers from group interview**

1. **CASE STUDIES**

The second phase of the research was to observe energy reduction projects and ascertain whether the potential barriers to implementation would appear. This would verify the potential list for relevance as well as completeness.

Between 2011 and 2012 around eight manufacturing energy reduction projects were carried out at a large aerospace manufacturing company in the UK of which three were observed as part of this reseach. This company has experience in energy reduction projects related to buildings and services but before 2011 no work had been carried out on improving manufacturing processes with the primary objective of energy reduction. The initial focus of improvement activities was on elementary part manufacturing, this in general being a much larger energy consumer than assembly. As part of this research the improvement of two processes were observed with examples of the barriers encountered given in the three case studies below.

Of the barriers listed in the earlier tables from literature and interview, 18 were observed to exist in the case studies. These observed barriers are shown in Table 4 as items [a] to [r]. Additionally two further barriers were observed which were not noted before, items [s] and [t].

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Observed barriers (number indicates source to original barrier)*** | | | | | |
| a | No sense of urgency (1) | h | Hidden costs (24) | o | Lack of process knowledge (38) |
| b | Inadequate training (11) | i | Access to capital (25) | p | Complexity of process (39) |
| c | Lack of accountability (18) | j | Risk (26) | q | Fear of impacting product quality (42) |
| d | Imperfect information (19) | k | Bounded rationality (27) | r | Fear of impacting health & safety (43) |
| e | Split incentives (20) | l | Form of information (28) | s | Not a priority |
| f | Adverse selection (21) | m | Inappropriate equipment (34) | t | Unclear who owns what |
| g | Principal-agent relationships (22) | n | Inadequate resourcing (35) |  |  |

Table 4 - Barriers to industrial energy efficiency observed

These barriers are shown in context in the following three case studies. The case descriptions provide insight to each project as well as reference back to table 4 the specific barriers observed. Barriers identified were included regardless of the frequency of occurrence. In no case did an actor specifically identify something that was not a barrier, only if it was, hence no conflicts were identified.

* 1. **Case 1: Industrial Drying Tank**

The surface treatments process was found to be one of the largest consumers of energy within the manufacturing company. The process consists of a number of enclosed treatments tanks through which parts pass in sequence. The final stage of the process is to dry the parts by forcing air over a heat exchanger and circulating it through the tank, see Figure 1. Investigations into the process found that the drying tank was one of the largest consumers of energy and that the main fan associated with the heat exchanger was always on, maintaining the tank at drying temperature even outside of production time. An improvement project was therefore launched to modify the controller such that the main fan was only on when required.

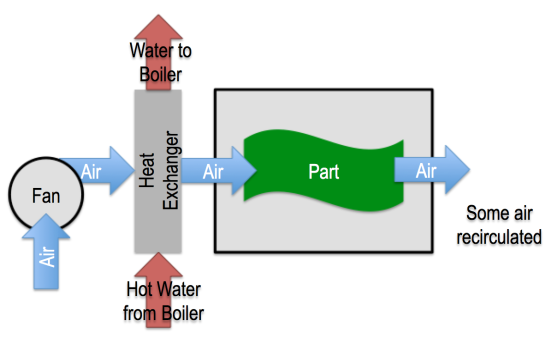


Figure 1 - Drying process

An important stage of the improvement approach is data collection. This was found to be quite difficult, with *incomplete information [d]* on the process – partly due to the *complexity [p]* of the process, and partly due to a *lack of access to equipment for collecting data [m]* (i.e. data loggers). This was exacerbated by having *no dedicated resource [n]* for collecting data – or for carrying out any subsequent improvements. Although the corporate *culture* and the *values* of individuals supported energy reduction activities, energy reduction was clearly *not a priority [s],* with other operational issues and other improvements always taking precedence over energy projects; there was *no sense of urgency [a]* for carrying out energy projects.

This discrepancy between corporate and personal commitment to energy reduction and the status of energy projects in the unit of analysis raised the question of who was *accountable [c]* for energy saving in a manufacturing perimeter. It was found that the Facilities function is usually responsible for energy reduction activities in this facility; it is Facilities who pay for energy and realise any benefits in reduction, however it is not empowered to act within a manufacturing perimeter. The Manufacturing Operations function is responsible for manufacturing process improvements but energy is outside its scope. So fundamentally there was *no clear owner [t]* for manufacturing energy reduction projects. Indeed, the relationship between Facilities and Operations could be considered a landlord-tenant relationship – which leads to the classic economic barriers of *principal-agent problems [g]* and *split incentives [e]* discussed previously.

When it came to carrying out the project, these barriers persisted and continued to cause delays to the project, particularly in terms of *resourcing [n]*, increasing the elapsed time of the project. In addition, those responsible for approving the improvements were concerned about the potential *impacts to product quality [q]* and to *health and safety [r]* and also that the project may incur *unintended expenses [h]* through disruption to production. These are valid concerns, particularly in the traditionally risk averse environment of aerospace manufacturing. However these fears could have been allayed but for a *lack of understanding [o]* of the combination of energy and manufacturing factors – which itself could be due to the *limited information collected [d]*, or due to a *lack of training [b]*. This in turn added *additional time and cost [h]* to the project while more data was collected and various mitigations put in place. It also caused the project team to select a *non-optimal improvement [f]* such that less energy was saved than could have been due to the inclusion of mitigations. In this case rather than only heating the enclosure when the product was present, a lengthy warm-up time was included to ensure the enclosure was always at temperature.

* 1. **Case 2: Industrial Spray Cleaning**

Another large consumer of energy in the surface treatments process is the spray cleaning tank. Here parts enter an enclosure and are sprayed with high pressure warm water to remove surface contamination from a previous manufacturing process (machining), see Figure 2. Two projects were identified on this process.

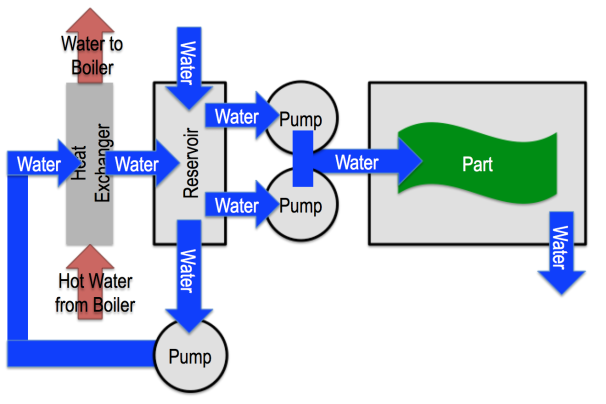


Figure 2 - Spray cleaning process

The first project focused on the spray pumps. The spray nozzles were fed by two high power pumps and it was found that the pressure required for all the nozzles could be provided by one pump alone. Thus the Maintenance function (part of Manufacturing Operations) decided to switch the operation of the pumps to duty and standby rather than both on continuously.

The Maintenance team has a good *understanding [o]* of the process and so a lot of the issues to do with *information [d]* and *risk aversion [j]* were avoided in this case. Maintenance was also able to provide *ownership [t]* for this project, since although it was still unclear who would benefit from the energy savings, Maintenance would clearly benefit from a reduction in maintenance work – and so Maintenance was happy to *fund [i]* and *resource [n]* this project.

However due to the responsibilities of the Maintenance staff this project was still *not a priority [s]* and the “day job” of attending breakdowns etc. always came first, meaning that the elapsed time for the project was long. Additionally *data collection [d]* was still quite difficult, although Maintenance could see the benefits of activities such as this and invested in new measuring equipment for future projects.

The second project focused on the circulation of water through a heat exchanger. The process requires the water to be at a certain temperature above ambient and so water is circulated by a pump through a hot water heat exchanger and into a reservoir from which it is pumped to the spray nozzles. As with the drying process, the circulation pump ensures that the water is always at the required temperature, regardless of whether it is required by the process or not. Due to the higher thermal mass of water, and the resulting longer warm-up (and also cool-down) time, the second project was this time to reduce the operation of the circulation pump to come on intermittently rather than continuously and so maintain the required temperature.

As with the drying process, this project too suffered from a *lack of ownership [t].* It was still not clear who would benefit from the reduced energy consumption and thus there was a *lack of access to capital [i]* for improving the process and a *lack of resource [n]* to carry out improvements. There were also *objections on health and safety grounds [r]* to altering the operation of the pump as it was believed it played a role in controlling bacterial growth. Initially this was believed to be due to a *lack of understanding [o]* of the biology involved or a *lack of understanding [o]* of the project proposal – thus the *form of information [l]* was changed to better communicate between functions, since each function was used to its own method of communicating improvement projects.

A lack of understanding can simply be due to a l*ack of knowledge [o]* on the subject matter, for example an unfamiliarity with the process or with energy saving practices. The lack of understanding here and in the example above could also be described in terms of *bounded rationality [k]*. Bounded rationality is the concept that an individual’s decision-making capability is based on the information presented to them (including *a priori* information and prejudices), the time they have to process that information and their cognitive capability. The limitations on each of these three fronts means that often *non-optimal decisions [f]* may be taken.

* 1. **Case 3: Ancillary Equipment in Metallic Machining**

The previous two examples focus on improvement to the surface treatments process, which was the initial focus of most of the work due to the level of consumption. Also within scope of the improvements is the machining process, where material is removed from metallic prismatic billets with rotating cutting tools to produce individual components, see Figure 3.

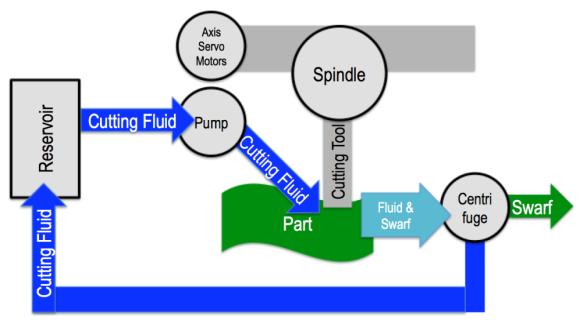


Figure 3 - Machining process

Typically a large portion (30-85% according to Dahmus & Gutowski 2004) of the energy used by the process comes from ancillary processes such as the coolant system and the hydraulic pumps rather than the cutting spindle. What can also be seen is these are typically independent of production rates since the ancillary equipment is left running outside of production time. This project focused on the use of the emergency stop (e-stop) functionality of the machine to cut power to the ancillary equipment rather than leaving the machine in an energised standby state between batches.

Initially there was much resistance to using the e-stop in this manner. In part this was due to *health and safety concerns [r]* but it was also due to anecdotal evidence that the machine was always difficult to start up again after a power cut, *impacting production [q]* and causing *unintended expenditure [h*. This shows both *risk aversion [j]* but also a *lack of understanding [o]* of the process. (The purpose of an e-stop is to safely stop the machine in the event of an emergency in a controlled manner, whereas a power cut is completely uncontrolled.) This was exacerbated by the fact that there was no record of testing the e-stop (*lack of information [d]*), which is something which should be regularly tested. The *complexity of the process [p]* also meant that no one really knew which pieces of equipment would be impacted by operating the e-stop (*lack of process knowledge [o]*).

The conflict between the project team and Operations here is based on the operational requirement that the machine be available as much as possible. Anything which could impact this availability was considered a threat – another example of energy saving *not being a priority [s]*. This also shows a *lack of accountability [c]* for the energy aspects of the process; the main concern of those operating the equipment is availability.

1. **DISCUSSION**

The case studies presented above describe each of the barriers from table 4 contextually, showing when and where the barriers occurred and what impact each barrier had on the project. By analysing the data collected on the case studies (interview notes, observations in research journal and project document analysis) it can be deduced that the impact of some barriers is to cause further barriers to exist - that is, there is a *causal relationship* between those barriers.

For example, in Case 1 the barrier of *no clear owner [t]* was found to exist for the energy aspects of the process. This is shown to lead to two other barriers of *split incentives [e]* and *principal-agent problems [g]*.

Causality is also shown to flow in the other direction too, with some barriers shown as being caused by other barriers. For example, in Case 1 the barrier of a *lack of information [d]* on the process is shown to be caused by a *lack of appropriate equipment [m]* for collecting that information and is also due to the *complexity [p]* of the process.

Thus it is clear that relationships exist between the barriers, with some barriers causing other barriers. By looking through the case studies given above, and through the other data collected throughout the enquiry, causal links between all the barriers can be demonstrated. A cognitive map is shown in Figure 4 based on the barriers observed in the case studies and these causal links.

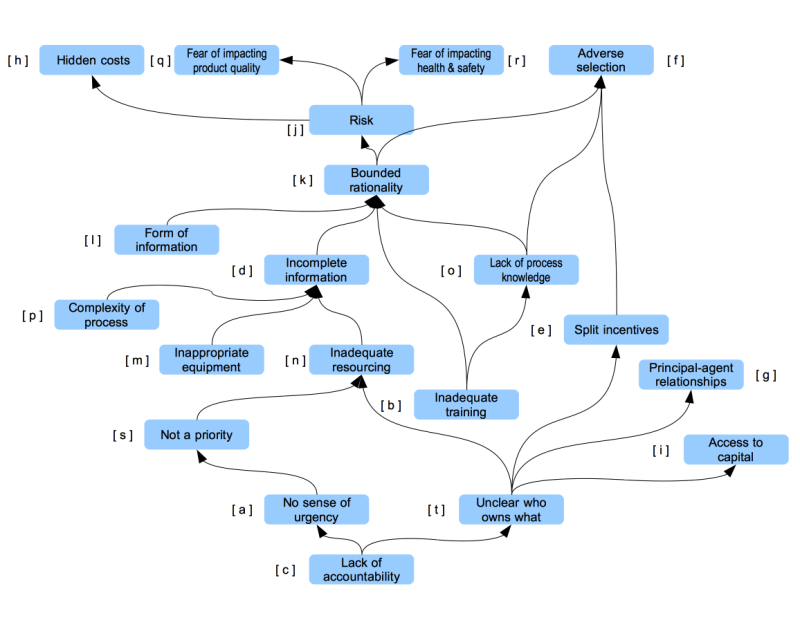


Figure 4 – Cognitive map of the barriers

This causal flow between barriers is important as the effect of overcoming specific individual barriers can be estimated. Causality implies that if we remove a *cause* then the *effects* will diminish or disappear.

For example, in Case 2 above the Maintenance function had access to good quality information about the process (*incomplete information* barrier removed compared to Case 1) and had a good understanding of the process (*lack of knowledge* barrier removed). This overcame the barrier of *bounded rationality* since good quality decisions could be made - which in turn meant that the proposal was high quality (*non-optimal improvement* barrier removed) and that risks were well-understood (*risk aversion* barrier removed).

However, when the barrier of *incomplete information* was removed another barrier became apparent - that there was *no dedicated resource* in the Maintenance function for carrying out the work because of the more important work being carried out on the shutdown (activity still *not a priority*). Thus the project was still delayed.

By understanding the causal flow, a picture of which barriers are the most significant can be built – that is, we can start to see which barriers provide a **root cause** for the other barriers. By identifying these key barriers interventions can be designed to tackle those barriers alone resulting in multiple barriers being overcome.

Figure 4 above shows causality flowing upwards in a kind of tree. At the end of the branches are outcomes, or barriers not causing any further barriers. Some barriers can stop execution permanently or temporarily e.g. *fear of impact to quality*, *lack of access to capital*. Other barriers can mean that the result of the project is not as good as it could have been, i.e. a *non-optimal solution* is selected.

At the bottom of the tree are the roots, the barriers which cause the other barriers to exist. The root causes are all related to accountability and ownership and are shown in Table 5 illustrated with examples.

|  |  |  |
| --- | --- | --- |
| Barrier | Example | Data Sources |
| Lack of Accountability | The site Energy Manager is responsible for reducing the site energy consumption but only has authority to act within a Facilities domain – that is, by improving facilities and services, such as buildings and switchgear. He is not empowered to act within a Manufacturing Operations perimeter. No-one is responsible for reducing energy demand. | *Journal; Project documentation (weekly reporting, emails); organisational structure; job descriptions/objectives.* |
| No Clear Ownership | Many improvements are identified but then delayed due to a lack of funding to carry out the works. This is because neither Facilities nor Manufacturing Operations can often agree whether the improvement is inside their perimeter: typically, Facilities claim that it is a manufacturing process improvement, and Operations claim that any benefit would be realised by Facilities. Both are correct, but neither will commit resources to achieve the improvement and own the improvement. | *Journal; Project documentation (weekly reporting, emails); organisational structure.* |
| No Sense of Urgency | A corporate target exists for energy reduction – but the planned date for achieving this is 2020. Additionally there has been little effort to break the corporate target down into individual business areas or distinct phases. There is thus a very limited impetus for people to work towards this target now – especially when other shorter term targets are at risk. | *Journal; Project documentation (weekly reporting, action trackers); cascade of corporate objectives* |

**Table 5 - Key barriers with illustrations**

These barriers have been identified as root causes since they are not the effect of other causes (there are no arrows going into them in Figure 4 above) and because they cause multiple other barriers (there are many arrows coming from them in Figure 4 above). These barriers are what hold all the other barriers in place. If these barriers ceased to exist then the other barriers may also cease to exist, or at least diminish in terms of their impact.

By looking at the tree it can be seen that the barriers at the top (i.e. the outcomes) are generally **operational** in nature; they are the barriers which would be experienced by people carrying out the activities.

The barriers at the bottom on the other hand are more **organisational** or strategic in nature. These barriers are not readily perceived by the actors within the unit of analysis since they do not directly affect them; it is the effects of the organisational barriers which they perceive. Thus there is little evidence for them in the data collected on the perceptions of individuals through the interview.

1. **CONCLUSION**

Having identified the absence of knowledge on energy related organisational barriers in the literature; the objective of this research was to identify organisational barriers to industrial energy efficiency which can reduce the ability of a manufacturer to improve. This research involved the identification of 44 barriers from a broad range of literature the existence of which within a specific manufacturing context was verified by observing three case studies within a large aerospace manufacturing organisation. These barriers came from generic literature on organisational change (including some literature on the failure of a change) and from specific literature on energy efficiency. Additional barriers were also identified by carrying out an interview with people from the manufacturing organisation who were previously involved in energy efficiency initiatives.

From the case studies eighteen barriers were found to exist and a further two were identified in the organisation making a total of twenty barriers to energy efficiency. The case studies were taken from metallic component manufacturing processes including machining and surface treatment.

By analysing the case studies it was found that these barriers were linked causally which is demonstrated through the rich narrative of the case studies presented in this paper and in particular through a cognitive diagram showing how each of the twenty barriers is linked. This causality implies that some of the barriers will be root causes to the other barriers. In the situation described by this paper these were found to be a **lack of accountability**, **no clear ownership** and **no sense of urgency**.

By identifying and subsequently focusing attention on the key barriers it is proposed that an organisation can develop interventions to be able to more effectively improve its energy efficiency.

For this specific situation the key barriers could be overcome by setting short-term (annual) energy objectives for manufacturing operations and by allocating appropriate resource to support energy reduction activities in that perimeter including a dedicated project manager and financial support for carrying out improvements. Setting objectives would make manufacturing operations *accountable* for reducing energy and also increase the *sense of urgency* for doing so. Having dedicated resource would ensure that activities had appropriate *ownership*.

From the theory perspective, the contribution of this research has been to develop greater understanding of the organisational barriers that can be present when attempting to improve industrial energy efficiency. Specifically, a comprehensive library of organisational barriers has been collated from varied literature sources and validated through application. Secondly, the barriers have been assembled into a novel cognitive map to indicate interrelationships between them that is absent in the literature. The research thus informs the direction of future research on this topic by both providing a framework which can be tested and also by identifying where research can be focused to have the greatest impact on practice. Finally, two new barriers of priority and ownership have been uncovered that are absent in the organisational energy literature.

From a practice perspective, the contribution of this research has been to demonstrate how energy efficiency projects can be hindered by organisational issues. Specifically, varied cases have demonstrated the issues present in specific energy reduction projects hence others can appreciate the detailed challenges they could encounter in their business. Secondly the cognitive map capturing causality can be used as a predictor of what new barriers may become more apparent in an energy reduction project once existing barriers have been overcome. Again, such insights for improvement engineers working on energy reduction have not been available to date. The cognitive map and the interrelationships it contains thus provide a useful tool for practitioners as they allow the impact of interventions or design decisions to be predicted at a project or organisation level. A practitioner informed by the cognitive map therefore will be able to design an energy efficiency project or even an organisational structure in a logical way which will remove or minimise the impact of barriers. Further, understanding what the key barriers are in the projects outlined in this research allows limited management attention to focus on the areas likely to have the greatest impact.

Further work could include verification of the success of applying these interventions within the manufacturing organisation developing further strategies for overcoming the barriers identified. Additional work is also needed to validate the list of barriers proposed outside the manufacturing organisation and in different industrial sectors.

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