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**Enablers for Improving Environmental Performance of Manufacturing Operations**

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**Abstract**

This work establishes how organizations can overcome barriers to sustaining manufacturing environmental performance improvement. There is a growing body of knowledge on energy and resource efficiency but there is a gap in how to counter barriers to enable technical and financial success. In this paper, barriers to energy efficiency adoption established from the literature are identified from 100 short-term manufacturing operations projects across 11 European plants over a three-year period. The longitudinal examination of multiple projects provides research insight absent from the literature that could be used by companies to enhance the outcomes of their improvement programs. Learning from early projects resulted in interventions to enable reduction in environmental impact and cost. The contribution of this research is the identification of enablers to sustain energy efficiency advance of: vision, objectives, operational responsibility, methods, training, people, community, equipment and data. The work has potential to better explain how organizational enablers mitigate barriers to environmental efficiency adoption to in turn reduce impact and to reduce cost.

**Managerial relevance**

This paper provides guidance on how to sustain environmental efficiency programs in manufacturing operations for engineering managers to extend lean production thinking rather than lean tools alone. In seeking to sustain improvements, companies may encounter process, people or technology barriers that hinder progress. The nine enablers grouped by people, process and tools are developed to aid sustainment: vision, objectives, operational responsibility, methods, training, people, community, equipment and data. The organizational enablers guide the focus of management action to mitigate potential barriers to performance improvement. Some enablers are not typical, such as the need for central funding for operational initiatives, transitional arrangements prior to strategy alignment and the need for a community of improvement champions. The benefit of these actions is that they focus on *how* to improve resource, especially energy, efficiency to complement existing work on *what* improvements to make or *what* tools to use.

**Index terms**: sustainable manufacturing, resource efficiency, energy efficiency, organizational barriers, organizational enablers

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I. Introduction

Manufacturing efficiency has developed from a focus on speed and quality of raw material transformation to broader resource efficiency in which all materials are the subject of productivity improvements, not just those used in the product. Early gains in resource efficiency (e.g. [25]) were a consequence of manufacturing operations efficiency actions and now come from direct focus on energy and other resources [27], [42] to reduce consumption and lower waste [24]. Importantly, failure to use resources efficiently misses commercial opportunities and resilience to scarcity [4]. Tools and methods (e.g [14]) guide the adoption of resource efficient operating practices [34] and technology [5] and their potential performance [46].

Improvement methodologies inform us technically on how to change but they do not inform how an organization should facilitate the change. As with the deployment of lean manufacturing philosophy [63], methods and tools are insufficient to replicate and sustain improvements [11]. Organizationally how to deploy the methods and tools demands tacit knowledge that is hard to detail and replicate. Understanding how to incorporate environmental improvement within the organization is important [35] but largely absent from literature. The literature focuses on *what* to do but not *how* to sustain resource efficiency improvements, particularly for energy, in manufacturing operations. The focus of this research is therefore on enabling improvement.

Engineering challenges must be overcome to implement efficiency practices but organizational barriers may impede their implementation. Understanding barriers preventing an organization from operating efficiently [22] can help managers implement sustainable practices [4]. Barriers may include differing motivations [9], resistance to learn [59] or lack of confidence a practice will achieve the savings claimed. Organizational enablers are features that can mitigate barriers. Reporting what enables success and what barriers [44] can arise through single case research (e.g. [36]) is common, however, investigation into multiple plants receives little attention. Multi-plant research is through external survey (e.g. [18]) or through public material (e.g. [24], [38], [64]) rather than using contextual manufacturing operations that could reveal how methods are deployed. There is a gap in how site success can be fostered which could be uncovered from multi-plant research. In contrast to the production efficiency practice of lean, there is little resource efficiency research on organizational practices to enable improvement.

The purpose of the research was to uncover how operations can enable resource efficiency advance. This complements the literature on technical advances. This research sought to better understand how organizations make use of processes, people and tools to embed resource efficiency into everyday improvement activity. The research contributes to resource efficiency by addressing how organizations can approach improvement rather than documenting what organizations have previously improved. To isolate what can be achieved within operations the separate strategic areas of product design and technology innovation were excluded. This is compatible with early stage lean manufacturing implementation.

The lens of organizational learning theory [1] was used to frame how to improve. This lens brings out the routines that organizations adopt to enable improvement and therefore addresses how, rather than what, to implement. Acknowledging that organizations incur barriers (such as those above) to progress, enablers provide actions to mitigate them. The managerial relevance is how organizations can engage in successful improvement actions. Resource efficiency could be an extension of lean, however, organizational learning provides foundations for resource efficiency and avoids confinement to extending lean tools. Energy was chosen for the focus as a common and significant resource consumed by manufacturers. Specifically, the research question posed was: *what are the enablers for manufacturing operations to sustain energy efficiency advance*.

The paper is structured as follows. First literature on organizational learning, resource efficiency practice and barriers is reviewed. Next, the deployment and outcomes of an improvement methodology within a corporation’s industrial energy efficiency network over three years is documented. Finally, the review of outcomes against the categories of process, people and tools leads to contributions of the organizational enablers for resource, in particular energy, efficiency adoption in manufacturing operations.

II. Theoretical background

Organizational learning theory can frame how resource efficiency activity can be sustained through routines that people adopt and embed within the organizational memory. Organizational learning has been applied to sustainability but has not been developed for operational resource efficiency sustainment. Barriers that hinder progress may be known but the organizational response is not. There is no framework in organizational learning to guide sustaining resource efficiency. Whilst it can be argued organizational learning covers the first two dimensions of the management, people and technology categorization used by Sarkis [47] for sustainable manufacturing investigation, it does not cover the third, technology.

This theoretical background uses organizational learning as the foundation and frames it with a process, people and tools categorization adapted from Sarkis [47]. Process is used to describe how activities are conducted, people refers to staff attributes on projects and tools refers to hardware and software to capture and manipulate data. The focus is therefore on facilitating the routines for process improvement, developing the capabilities of people and providing the availability of data through tools. The analysis of the literature sets the foundation on which to ascertain theenablers for manufacturing operations to sustain advance.

*A. Organizational Learning*

Organizational learning theory is a means by which changes in cognitions, routines and behaviors can be investigated [1]. Routines include rules, procedures and strategies [29] and can be used to frame investigation into how an organization may tackle the promotion of resource efficiency practice. Davies [8] is one of the few to use organizational learning for environmental improvement in manufacturing. Figure 1 is a simplification of Davies' model by focusing on production operations and removing product development with outcomes implied rather than explicit. The linkages shown are the dominant ones, other weaker interactions will exist. Vision [28] and Strategic-operational alignment [56], [65] are additional to the Davies model. The top part of the figure relates to people aspects, the lower aligns to process whilst the tools and technology are absent from this body of knowledge. The model shown in Figure 1 is the main theoretical foundation of the work and is explained alongside barriers next.



Figure 1. Aspects of organizational learning and their associated barriers

Organizational learning through outcomes captures the inter- and intra-organizational development through teams and wider communities [8], [17]. Such learning (shown at the top of figure 1) in turn supports the individual learning in operations. Individual learning may be through experimentation or adoption of standard practices, noting that local adaptation [59] creates a tension in deviating from standard. The subsequent routines and behaviors distinguish between knowledge retention by an individual and knowledge retained by an organization independent of people and staff turnover [29]. Alignment to a standard method of working [53] coupled with individual learning [16], [29] and experimentation offers the opportunity to overcome local barriers and improve outcome. Now referring to the lower part of Figure 1, the role of strategic management in adapting and integrating skills and competence to develop in turn new routines [56] ensures there is strategic alignment [65]. Whilst knowledge here is about the value-adding, core competitive processes, the analogy can be drawn for strategic-operational alignment of the organizational structure and deployment of improvement processes which is absent in the resource efficiency literature.

Barriers receive some attention in organizational learning [1] focusing on how competences (or knowledge) are developed and retained. In product development, barriers relate to competence, culture, hierarchical structure and patriotism [17] which link to organizational design, work systems and reward systems. Patriotism will impact on whether learning from elsewhere is adopted, adapted or resisted. Work has been on the individual [3] behavioral barriers rather than the barriers within the structure of the organization such as equipment or information. The structural barriers and the subsequent organizational response is absent from the literature. Different plants have the potential for diversity of reporting [7], lack of spontaneity [53] to maintain alignment and the unwillingness of the receiving teams and individuals to learn [59]. Such factors could hinder adoption of new practices but may be less likely to surface in a single corporate structure, with similar working practices. These barriers are initially mapped onto the organizational learning framework in figure 1 as described and enhanced using the engineering management literature in the sections that follow.

Learning through outcomes [1] lends organizational learning to the investigation of resource efficiency adoption. It has been used to investigate how companies approach their journey towards sustainability, for example through environmental technology [16] and transition strategy [8]. Senge [51] adapts organizational learning for a sustainability approach using tools, rather than systematic methodologies, to examine the wider system. Overall, the field emphasizes the importance of processes and people not technology and IT systems. The resource efficiency literature neglects the organizational retention of routines whilst the organizational learning literature neglects the operational aspects of sustaining resource efficiency. The Process, People and Tools sections that follow consider how organizations can pursue sustainable manufacturing.

*B. Process*

Process improvement practice is often expressed in lean production system [63] language which centers on process flow and waste removal. Waste includes excess inventory or unnecessary handling [55] and extends to eco-efficiency [20] including waste of energy [25] and water [52]. Process improvement methodologies combine steps with supporting tools to adopt as routines or standard operating procedures.

The development of operating habits (or culture) as well as an infrastructure to support improvement is a precursor to success. Sustaining success is only achieved when the lean philosophy forms a unique approach [30] to the corporate strategy [11] which supports the vision and alignment aspects in Figure 1. In contrast to lean deployment, the infrastructure and habits for resource efficiency receive little attention.

Works on barriers distinguish between different types, including individual behavioral barriers and company level organizational barriers [54], [62] thereby excluding technical limitations as barriers. Work in the energy intensive industry identifies risk related barriers [57] (e.g. deliberately or accidently stopping production) as some of the most significant whilst others emphasize the social context of individuals and organizations [40]. Turesky & Connell [60] use failures to identify ten barriers for lean production and design an improved intervention, however, the equivalent work in the resource efficiency field is lacking.

The categorization of process, people and tools can be used for the underlying cause of a barrier from the eco-efficiency literature to add depth to the organizational learning barriers identified earlier. The process categorization shown in Table 1 uses Lunt et al’s [32] collation of barriers to energy efficiency as the foundation. The barriers are matched to a category based on the primary reason they could exist.

Table 1. Barriers and definitions for process

|  |  |  |
| --- | --- | --- |
| **Barrier** | **Barrier definition** | **Reference** |
| **Process** |  |  |
| Accountability | Absence of senior management sponsorship | [28], [60] |
| Ownership | Lack of responsibility through project work breakdown structure | [32], [60] |
| Priority | Priority for a project is not maintained | [28], [32], [54], [57] |
| Principal-agent | Function consuming energy is not accountable for saving or managing energy | [22], [54], [57] |
| Split incentive  | Function investing (time, money) in energy improvement receives no benefit  | [37], [54], [57] |
| Risk | Perceived negative impact on another activity | [37], [54], [57] |
| Selection | Picking a sub-optimal project to progress | [9], [54], [60] |
| Hidden costs | Business case challenged, incomplete or not believed | [9], [22], [37], [54], [57] |

The resource and energy efficiency practice work is technically backward looking at what has been achieved and neglects the future habits and routines required in contrast to the people focus that is critical for lean. There is potential to frame energy efficiency work beyond lean and change management terms by using organizational learning [16] to distinguish between the technical process and tools and the organizational support to sustain improvement outcomes. Therefore, people aspects are discussed next.

*C. People*

The capabilities and behaviors of people working on improvement projects receives attention in lean and to some extent environmental manufacturing (e.g. [45], [47]). The development of people through training [43], how teams are developed and how they are influenced by the wider company behavior and values are less commonly reported. Environmental efficiency has been a technical challenge [26] (e.g. waste heat recovery [32]) rather than how to enable habitual energy efficiency improvement. The “what” question has been addressed and attention needs to be given to “how” [35].

Learning can be drawn from the change management literature (e.g. [50]) and aligned to lean and green methodologies. The creation of a vision [28] provides direction for people but can appear intangible without methodologies that show how targets can be used to drive a sense of urgency in the organization. Literature on barriers to energy efficiency adoption addresses hurdles for change. Kotter [28] identifies barriers relating to urgency, vision and anchoring change. Some works use economic theory to describe lack of willingness to change (e.g. [9]) whilst others take a market perspective (e.g. [22]). Work covers technologies [26], energy efficiency [44], [54] and lean supply chain [37] and some split between internal and external barriers [41] and the causal links between them [32]. The term barrier describes what could potentially prevent progress and learning. The barriers for people collated from the literature are summarized in Table 2. These are more detailed than those available within the organizational learning field and offer tangible focus compared to barriers of, say, culture or diversity.

Table 2. Barriers and definitions for people

|  |  |  |
| --- | --- | --- |
| **Barrier** | **Barrier definition** | **Reference** |
| **People** |  |  |
| Urgency | No sense of urgency from manufacturing operations to undertake project | [28], [32] |
| Resourcing | Insufficient people available to undertake a project | [32], [57] |
| Training | Lack of access to training to address any knowledge and skills gaps | [32], [60] |
| Knowledge | Insufficient knowledge and skills are present in a project team | [32], [37], [57] |
| Bounded rationality | Insufficient data available to make a good choice of which project to carry out | [9], [54] |
| H&S fear | Resistance exists to projects on the grounds of health and safety | [32] |
| Quality fear | Resistance exists to projects on the grounds of impacting on product quality | [32] |

*D. Tools*

The inclusion of ‘green’ within lean [19], [37] helps organizations to see waste previously hidden. The resource efficiency field places emphasis on tools to extend lean, such as green VSM [14], combine approaches with lean [42] or emphasize quality [67]. Returning to the earlier process discussion, how process improvements are conducted [27] avoids narrow focus on tools alone that have limited short-term success [11].

Resource efficiency actions are distinct from process improvement actions such as batch size reduction and mistake proofing. Resource efficiency actions reduce or remove energy, water, etc use by, for example, powering down machines when not required or using natural ventilation rather than forced ventilation for drying. Databases provide examples of past company resource efficiency improvements (e.g. [6], [10], [13]) to inspire action but they do not inform the process of conducting improvements or promoting future habits, routines and behaviors. Tools and equipment to provide data receive little attention in the resource efficiency field and even less in the organizational field despite reliance on data to carry out the analysis commonly reported.

Barriers were presented earlier for people, such as training, and for process, such as accountability. Again, using Lunt et al’s [32] collation of barriers as a foundation, Table 3 lists technology or tools barriers which may arise from the availability of equipment or data gained only from the resource efficiency field.

Table 3. Barriers and definitions for tools

|  |  |  |
| --- | --- | --- |
| **Barrier** | **Barrier definition** | **Reference** |
| **Tools** |  |  |
| Capital | Insufficient funds available for purchasing equipment | [54], [57] |
| Equipment | Insufficient tools or materials available to undertake a project | [32], [57] |
| Complexity | Insufficient capture of the operation of the system  | [32] |
| Form of information | Inability to appropriately interpret data to undertake a project  | [40], [54] |
| Incomplete information | Insufficient data available to undertake a project | [9], [37], [54], [57] |

*D. Conclusions*

The literature review considered how organizations can respond to the challenge of fostering resource efficiency activity. The resource and energy efficiency literature is strong on what practices have been applied, what tools are available and what barriers could be encountered. There are many examples of the successful introduction of more resource efficient practices but they demonstrate outcome rather than an approach for adoption by others. How organizations can embed efficiency activity and counter potential barriers is absent.

Lean production requires the development of habits within an infrastructure, however, such knowledge is absent for resource efficiency. Organizational learning could address this gap given the attention to developing knowledge, developing habits and alignment activity to the strategic vision. However, there is a gap in organizational learning for resource efficiency activity, particularly on the operational aspects of how to sustain it. The model of organizational learning in Figure 1 has resource efficiency categories of people (upper elements) and process (lower elements) but currently lacks tools.

There is potential to contribute to the resource efficiency and organizational learning fields. For resource efficiency, the research can extend knowledge from *what* can be done to *how* to organize and embed activity. For organizational learning, knowledge can be uncovered on operational sustainment of resource efficiency and the response to known barriers. The organizational learning model along with the people, process and tools categorization will be used next to frame how an organization can enable environmental improvement.

III. Research Method

The research focuses on the enablers for sustaining resource efficiency activity and overcoming organizational barriers that could arise. Case-based research [12] is appropriate to gain the detail of activities and changes. Whilst repeated deployment across organizations could lend itself to a positivist viewpoint and associated data collection techniques, the potential enablers are poorly understood, as are their links with barriers. To uncover the enablers for success, the unit of analysis is an improvement project carried out by a multi-disciplinary team in manufacturing operations. Organizational learning theory is used to frame the research and examine routines/standard operating procedures and resulting outcomes from an operations perspective.

A large European aerospace manufacturer was chosen as the source of the case data. It was embarking on an enterprise-wide resource efficiency program and therefore could provide insight into the challenges faced and how these were overcome. Supporting this selection was the potential access to multiple projects across 11 plants, the uniformity of procedures across those sites and the existence of a mature lean program. The latter is of note as any improvements can be attributed to the resource focus rather than mixed with the development of a general improvement culture. Other known companies could have been approached but did not have the characteristics of early stage of implementation, clarity of the improvement approach, number of projects expected or uniformity of operations collectively. It should be noted that one author was employed by the enterprise as the energy efficiency network lead.

As background, with strategic corporate responsibility objectives and success of deploying energy efficiency initiatives at one plant, a network of energy efficiency ‘focal points’ (champions) had been created and the learning developed at the one plant was being replicated across 10 others. The research captures numerous projects in the first years of the network as shown in Table 4. The company’s mature lean program demonstrated their ability to adopt pan-company initiatives and accept centralized methods. This research could therefore focus on organizational enablers for sustaining an energy efficiency focus to complement the current labor and materials productivity focus. The improvement methodology was created from Toyota’s ‘six attitudes’ and was consistent with the company’s deployment of lean. Alternatives such as Plan-Do-Check-Act (PDCA) cycle [49] were not within scope given the existing improvement methodology which was aligned to the organizational structure and metrics.

Table 4 Projects in the data collection

|  |  |  |  |
| --- | --- | --- | --- |
|  | 2013 | 2014 | 2015 |
| Plant A | 8 | 4 | 7 |
| Plant B | 1 | 8 | 3 |
| Plant C | 0 | 1 | 1 |
| Plant D | 1 | 5 | 2 |
| Plant E | 2 | 0 | 1 |
| Plant F | 3 | 2 | 2 |
| Plant G | 3 | 3 | 9 |
| Plant H | 9 | 4 | 7 |
| Plant I | 1 | 1 | 0 |
| Plant J | 0 | 0 | 2 |
| Plant K | 1 | 4 | 3 |
| Total | 29 | 32 | 37 |

Sources for savings, barriers and enablers are shown in Table 5. Firstly, progress and achievement were tracked by the network lead. The documents analyzed were standard project reports (initial business case; project management inc. methods, project plan, progress; final report) and improvements achieved (changes made, changes in performance). One instance of each document existed for each project. Secondly, information not tracked by the project reports was captured in the company project journal which contained ongoing project specific and general network information. Sources included telephone and email support; reviews with all network focal points three times per year; individual plant project reviews, four per year.

Table 5 Data collection type against data collected

|  |  |  |  |
| --- | --- | --- | --- |
| Source \ Data type | Savings | Barriers | Enablers |
| Business case | x |  |  |
| Project management |  | x | x |
| Final reports | x |  |  |
| Performance to target | x | x |  |
| Support |  | x |  |
| Review network |  | x | x |
| Review plant |  | x | x |

Criteria and method for extraction of the data were as follows. Savings were defined as resource (specifically energy) reduction attributed to each specific project. Savings information is traceable to the target in each business case (specification) document and the savings achievement from the performance improvement passed on for management reporting and traceable back to the final report.

The criterion for identifying a barrier was a reported challenge that deviated expected progress against timeline or target. Literature (Tables 1 to 3) was used for structure against specific process, people and tools barriers. Barrier information was manually assembled from the reasons for project deviation, the issues logged from support calls (e.g. inability to access data) and the focal point group reviews and individual team meetings (e.g. prioritization issues). For example, if a network review meeting reported staff availability hindering a project the barrier of ‘resourcing’ would be classed as ‘detected’. If the hindrance had a significant impact on project timeliness or savings it would be classed as ‘strong’. Here the difference is between a person struggling to dedicate sufficient time versus being reassigned elsewhere. The latter is objective (whether they are available or not) whilst the former is judged by credibility to report to seniors.

The criterion for identifying an enabler was a documented practice that was presented that supported the project progress. Literature (Figure 1) was used for structure where possible and exceptions noted against the initial interventions of method, support and targets. Enabler information can be traced to the methods (e.g. metering for data collection) and the reviews (e.g. operational responsibility through maintenance). Standard company documentation demanded consistent presentation of data and the reviews at network level provided more consensual views of activity than could be gained through detailed site level review. Examples of enablers are central funding to address equipment availability and presence of an improvement methodology (for routines). Equally, the absence of an aspect was recorded, for example that sites did not adapt the improvement methodology to meet local conditions. Documents detailing the changes and improvements were validated by senior signatories giving independence and weakened potential for bias.

In summary, the analysis drew out the presence of barriers and what mitigating conditions existed, i.e. enablers. Those in the organization learn what barriers may occur and use interventions to minimize them.

IV. An Industrial Energy Efficiency Network

*A. Network catalyst*

The research centers on a large European aerospace manufacturer spanning 11 plants. One plant (Plant A) demonstrated success in an energy efficiency program prior to 2013 which spawned an industrial energy efficiency network encompassing all plants. Learning from Plant A, initial interventions were generalized as methodology, supporting organization and targets. From the launch of the network, this research captures what barriers existed and what organizational changes enabled projects. In the narrative, a barrier is identified using italics. The three initial interventions are refined based on the findings.

*B. Network launch*

A three-part strategy was initiated by the central manufacturing engineering function for 2013 consisting of (1) lean improvement initiatives, (2) identification and implementation of best available techniques and (3) development of new technologies. Focal points (‘champions’) were nominated by each plant manager to implement local projects within the wider network strategy. A standard methodology was used by each plant to enable them to identify and implement improvements with a focus on points (1) and (2).

The network fostered a community to complement the established lean improvement organization which was standardized across the plants and universally accepted. The improvement methodology from Plant A was adopted as a standard set of methods (set of documented routines). Training materials with example applications were developed and an external provider deployed them to develop the knowledge of the other ten plants. Standardization was needed to embed the approach into the organizational structure which would be more effective than passing experience from one individual to another.

The role of the network lead was to support the community of focal points and their teams in selecting appropriate projects and targets. Teams would evaluate their performance against target and share their learning. Experience of organizational barriers from Plant A prompted interventions to counter three typical early barriers of lack of *accountability*, no sense of *urgency* and no clear *ownership* by developing clear objectives. The network lead coordinated central reporting and equipment funding and used common target setting. Each plant agreed their own objectives for a reduction in annual energy consumption. A small degree of friendly competition between plants ensured targets were stretching but achievable.

*C. Network evolution*

Based on the barriers identified in Tables 1, 2 and 3, it was expected that challenges would arise. The target setting, methodology, and use of the existing lean production infrastructure were initial enablers for improvements. The data collection sought to detect barriers and monitor resolution. During the period, interventions were made to overcome barriers encountered.

V. Results

Table 6 summarizes energy efficiency savings over three years. Figures drawn from MWh savings have been normalized against the savings target of Plant A for confidentiality, therefore the performance is declared relative to target. Savings are drawn from absolute savings not relative to production. The normalization allows direct comparison without having to account for gas/electricity mix or local energy costs. For example, Plant F in 2013 met its target savings (100%), Plant H made some savings but less than anticipated (78%) and Plant G saved more than double the target (235%). Moderate production volume increase is noted during the period across all plants. Sites carried out many projects and savings to target variance dropped over the three years. It is too early to judge whether sites became better at setting realistic targets or whether projects became more challenging. There was no evidence that returns decreased and resulted, as Perroni et al. [41] suggest, in less enthusiasm for further projects. Discussion later shows that progress became more challenging in some sites. Whilst barriers to energy efficiency were experienced, in general the barriers did not prevent success overall.

Some plants did experience significant problems. Plant C did not set a target because of inadequate *resourcing* (people and funding) for carrying out projects in 2013. Whilst the resourcing issue persisted in subsequent years it did not prevent projects from proceeding. Inadequate *resourcing* became a severe issue for Plant E and projects were not started and so no savings were achieved. The project Plant J initiated in 2013 was due to deliver in 2014 and so had no target or savings for that year and later delayed this to 2015.

Whilst the actual savings cannot be declared, some were very significant. Anecdotally, this is consistent with companies with established lean programs; subsequent application of lean thinking to other resources such as energy realizes large savings. The projects covered the breadth of the STRE3TCH methodology and included stop (process for safe powering down of assets when not required), repair (better management of compressed air), reduce (reduction in process requirements for paint shop air handling) and trade (waste heat capture and reuse).

Table 6. Energy savings per plant per year

|  |  |  |  |
| --- | --- | --- | --- |
|  | **2013** | **2014** | **2015** |
| **Plant** | **Savings Target** | **Savings Actual** | **Savings to Target** | **Savings Target** | **Savings Actual** | **Savings to Target** | **Savings Target** | **Savings Actual** | **Savings to Target** |
| **Plant A** | 1.000 | 1.712 | 171% | 1.667 | 1.133 | 68% | 1.033 | 0.691 | 67% |
| **Plant B** | 0.001 | 0.006 | 500% | 0.542 | 0.121 | 22% | 0.050 | 0.050 | 100% |
| **Plant C** | - | - | - | 0.104 | 0.104 | 100% | 0.026 | 0.026 | 100% |
| **Plant D** | 0.375 | 0.083 | 22% | 0.200 | 0.290 | 145% | 0.375 | 0.588 | 157% |
| **Plant E** | 0.125 | 0.122 | 98% | 0.347 | 0.000 | 0% | 0.347 | 0.000 | 0% |
| **Plant F** | 0.208 | 0.208 | 100% | 0.683 | 0.891 | 131% | 0.833 | 0.653 | 78% |
| **Plant G** | 0.167 | 0.392 | 235% | 0.833 | 1.383 | 166% | 1.500 | 2.568 | 171% |
| **Plant H** | 0.286 | 0.224 | 78% | 0.208 | 0.292 | 140% | 0.146 | 0.109 | 75% |
| **Plant I** | 0.108 | 0.108 | 100% | 0.167 | 0.242 | 145% | 0.083 | 0.083 | 100% |
| **Plant J** | - | - | - | 1.600 | 0.000 | 0% | 2.500 | 1.292 | 52% |
| **Plant K** | 2.917 | 4.167 | 143% | 2.000 | 5.317 | 266% | 0.138 | 0.138 | 100% |
| **Average** |  |  | 161% |  |  | 131% |  |  | 91% |

Some barriers were detected and some were not. No new barriers were uncovered. Barriers were identified at all plants. Table 7 combines the process, people and tools categorization from the theoretical background to chart the detection of barriers by plant, by year. The analysis of barriers shows that many existed at each plant and similar barriers were appearing. Some barriers became more evident over the years. Where the table has no entry, weak or no evidence for the barrier was captured. For 1/light shade then the barrier was detected. For 2/dark shade the barrier was detected and evidence showed a strong (negative) impact evidenced through project delay (against project plan) or underperformance (against improvement target in project business case).

Table 7. Capture of barriers by plant by year

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Barrier** | **Year** | **Plant A** | **Plant B** | **Plant C** | **Plant D** | **Plant E** | **Plant F** | **Plant G** | **Plant H** | **Plant I** | **Plant J** | **Plant K** |
| Process | **Accountability** | 13 |   |   | 1 |   |   |   |   |   | 1 |   |   |
| 14 |   |  | 1 | 1 | 1 |  |   | 1 | 1 | 1 |   |
| 15 | 1 |   | 1 | 1 | 2 |   |   | 1 | 1 | 2 |   |
| **Ownership** | 13 |   |  |   |  |   |  |   |  |   |  |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   | 2 |   |   |   |   | 2 |   |
| **Priority** | 13 |   |  | 1 |  | 1 |  | 2 |  | 2 |  | 1 |
| 14 | 1 |  | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 |
| 15 | 2 |   | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 |
| **Principal-agent** | 13 |   | 1 | 1 | 1 | 1 |  | 2 | 1 | 1 | 1 |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Split incentives** | 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 15 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| **Risk** | 13 |   |  |   |  |   |  |   |  |   |  |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
|  | 13 |  |  |  |  |  |  |  |  |  |  |  |
| **Selection** | 14 |  |  |  |  |  |  |  |  |  | 1 |  |
|  | 15 | 1 | 1 |  |  |  |  |  |  |  | 1 |  |
| **Hidden costs** | 13 |   |  |   |  |   |  |   |  |   |  |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   | 2 |   | 1 |   | 2 |   |   |   |
| People | **Urgency** | 13 |   |   | 1 | 1 | 1 |   | 1 | 1 | 1 |   |   |
| 14 | 1 |  | 1 | 1 | 1 |  |   |  | 1 |  |   |
| 15 | 1 |   | 1 | 2 | 2 |   |   | 2 | 1 |   |   |
| **Resourcing** | 13 |   | 1 | 1 | 1 | 1 |   |   |   |   |   |   |
| 14 |   |  | 1 |  | 2 |  |   |  |   |  |   |
| 15 | 1 | 1 | 1 |   | 2 |   |   |   | 1 | 2 |   |
| **Training** | 13 |   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Knowledge** | 13 |   |   | 1 |   |   |   |   |   |   |   |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Bounded rationality** | 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **H&S fear** | 13 |   |   |   |   |   |   |   |   |   |   |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Quality fear** | 13 |   |   |   |   |   |   |   |   |   |   |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| Tools | **Capital** | 13 |   |  |   |  | 1 | 1 |   |  |   |  |   |
| 14 |   |  |   |  |   | 1 |   |  |   |  |   |
| 15 |   |   |   |   |   | 1 |   | 1 |   |   |   |
| **Equipment** | 13 |   |   |   | 1 |   | 1 |   | 1 |   |   |   |
| 14 |   |  |   | 1 |   | 1 |   | 1 |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Complexity** | 13 |   |   | 1 |   |   |   |   |   |   |   |   |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Form of information** | 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 |   |  |   |  |   |  |   |  |   |  |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |
| **Incomplete information** | 13 | 1 | 1 |   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 14 | 1 |  |   | 1 |   |  |   |  |   |  |   |
| 15 | 1 |   |   |   |   |   |   |   |   |   |   |

VI. Discussion and Managerial Implications

The research sought to answer the question of what enablers can sustain energy efficiency advance in manufacturing operations. Interventions of methodology, supporting organization and targets were deployed prior to the network start in 2013. Table 7, however, shows barriers to progress of *form of information, incomplete information, bounded rationality* and *split incentives* were still detected at most plants, including Plant A. This indicates ineffective interventions rather than a lag between deployment and impact. Significantly, barriers related to data and decision making rather than funding or subsequent cost saving.

*A. Process*

An appropriate vision to drive a sense of *urgency* is well established for change management. Plants set their own short-term targets based on expected absolute annual savings potential and individuals’ performance reviews. At the time, operational targets could not be directly linked to the corporate 2020 vision targets. The separation of reward systems from organizational design [17] is counter to the established thinking of linking targets to vision and strategy. This transitional arrangement fostered engagement and accountability and used a tangible operational vision. The teams learnt through outcomes [1] without direct link to strategy to build confidence in the new routines as they were embedded into the organizational structure. Some plants showed greater depth of integration of the improvement work such as specifying new capital equipment. ‘Vision’ and its interpretation is therefore established as an intervention to enable energy efficiency projects.

Process-related barriers such as clarity of *ownership* and *principal-agent* relationships were rarely observed given clear target setting and supporting infrastructure of equipment and data provision. In the first year, the *principal-agent* issue was avoided as plant managers accepted that projects would benefit the company even though those carrying out the work may not see the benefit. However, over time barriers re-emerged as other initiatives competed for plant managers’ attention. Drawing on the initial targets intervention, ‘Objectives and targets’ is therefore confirmed as an intervention to enable energy efficiency projects.

The lack of *priority* barrier was detected in most plants in year three with people-related resourcing issues persisting suggesting a failure of the ‘targets’ intervention. Agreeing targets, which are time-bound and regularly reported, was a means of ensuring energy savings projects remained a *priority* and promoted a sense of *urgency*. When the initiative was launched, energy appeared in top level performance indicators motivating managers to avoid a “red” condition. This is compatible with the need for organizational alignment for lean and sustainability between seniors and operational staff [31]. However, following organizational changes in 2013 energy was only reported locally hence lack of *priority* became apparent, similar to resistance in lean programs with mixed messages on objectives [33]. ‘Objectives and targets’ is therefore refined into both corporate and local level interventions to enable energy efficiency projects.

Barriers became worse in some sites. Those same sites under-performed against target. All sites suffered the *split incentives* barrier because the cost of energy is allocated to production as a fixed chargeback and not by consumption. Despite neither punishing excessive consumption nor rewarding savings, performance improvements were achieved in all plants, noting that each focal point reported being challenged on the financial return for effort spent. Day-to-day prioritization of production output delayed project completions. It was difficult to develop an appropriate intervention since the targets for energy reduction were at project, not production, level. Not all process barriers were detected. *Risk* and *hidden costs* were infrequently observed. ‘Targets’ is still considered an important intervention to enable energy efficiency projects. Potentially ‘consumer pays’ to internalize consumption with targets could be an enabler for energy efficiency but insufficient data was available to be conclusive.

In years two and three, some focal points were replaced with Industrial Maintenance function staff and all subcontractors reported to them. This was the most appropriate function for enabling the strategy but the lack of *accountability*,lack of *priority* and *split incentives* barriers were present throughout the period across many sites, hampering progress. This development shows the growing role of maintenance in energy efficiency in the company, however, the priority for maintenance continues to be the consistent operation of plant. ‘Operational responsibility’ is therefore established as an intervention to enable energy efficiency projects.

The initial enabler of a standard improvement methodology was disseminated through standard *training* resulting in standard practice deployment. There was evidence of the development of routines [2] becoming embedded into the organization [29]. In project documentation, emails and meeting notes, no resistance was detected in teams. The company’s history of deployment of standard methods, no competing methods and proven earlier success would have been influential here. Standard (or ‘template’) ways of working can overcome resistance to adoption by demonstrating results and evidence of efficacy [23]. Industrial energy efficiency here shares the same value of linking to lean production demonstrated by other authors (e.g. [14]). The company used ‘STRE3TCH’ (STop, REmove, REpair, REduce, Trade and CHange) based on the Toyota ‘6 attitudes’ approach to resource efficiency. The success at a company synonymous with lean provided confidence that fear of impacting on product quality (*quality fear*) and fear of impacting on health and safety (*H&S fear*) barriers would be avoided. The focus on the underlying causes of problems helped avoid adverse *selection*, e.g. Maintenance bought expensive efficient motors with lower lifetime costs rather than purchasing cheap motors even though the budget holder faced higher cost. Another example was compressed air where Maintenance sought demand reduction and implemented appropriate maintenance routines rather than only focus on air compressor efficiency. Challenges in applying the methodology because of *form of information* and *incomplete information* for decision making are addressed later. The view of lean thinking and lean infrastructure in energy efficiency improvement as opposed to lean as a source of tools has potential for further research. Ōno [39] advocates lean philosophy as having the greatest impact when it is integral to corporate strategy. ‘Methods’ is therefore confirmed as an intervention to enable energy efficiency projects.

*B. People*

Turning to people, *training* was delivered so that everyone had the same level of knowledge and each could apply the energy efficiency methodology. Training, using examples, overcame the *bounded rationality* barrier to make informed decisions with confidence. The range of staff experience meant abilities varied. The barrier of lack of *knowledge* was anticipated but was rarely experienced due to appropriate nomination of focal points and the network collaborative behavior. ‘Training’ is established as an intervention to enable energy efficiency projects.

Each focal point worked on energy efficiency in addition to their primary role. It was found that those in Maintenance were the most able to implement improvement projects due to their process knowledge and knowledge of energy consumption. These roles varied in seniority and, crucially, time available. Thus, *inadequate resourcing* appeared as a barrier at plants with less than 10% of a full time equivalent employee available which led to project delays. Some plants secured subcontract staff funding in response. Plants with dedicated people far exceeded their targets, e.g. Plant D. In some sites lack of *priority* led to lack of *resourcing*, with Plant E and Plant J having their focal point reassigned to other projects. ‘People’ and associated funding (‘resourcing’) is therefore established as an enabler to sustain energy efficiency projects.

Targets were set to avoid the lack of *accountability* barrier and the sense of *urgency* barrier. The nomination of a focal point by each plant manager initially served to overcome the clarity of *ownership* and lack of *priority* barriers. Bringing focal points together in a network provided a community for sharing, learning and escalation. The network provided a community in which the sense of urgency could be fostered and momentum built. Challenges in adaptation to local conditions [59] or “not invented here” attitude [17] were not detected. This illustrates the strength of a community of practice by having “interdependent practitioners having common work practices, common interpretations of joint endeavours” [53] unrestricted by functional or national organizational boundaries [48]. Similarly, in transferring knowledge, no resistance to change or nationality differences were detected. The multi-functional representation in the teams provided a breadth of knowledge locally. The strength of the network was illustrated in its first year when one focal point repeatedly assisted another plant. ‘Community’ is therefore established as a cross-cutting and reinforcing intervention to enable energy efficiency projects.

The operational focus of the improvement teams to deliver to target was evidenced by the achievements of multiple projects at each plant. The repeated applications of the methodology allowed staff to learn from the experience and develop competence. Such findings extend the organizational learning work of Davies [8], Gavronski et al. [16] and Senge [51] in sustainability by uncovering the detail of activities and related barriers impacting on performance and environment and in doing so countering diversity [7], willingness or variation in reporting.

*C. Tools*

First examining shop floor hardware, it was anticipated that access to equipment to measure process performance would support energy efficiency improvement work. Therefore, the barrier of *access to capital* was overcome by providing central funding for environmental projects. Some focal points reported problems of inappropriate *equipment* and accessing funds caused delays. Training was provided to improve staff understanding of how to access *capital*, removing this issue as a cause for project delay. Most barriers related to tools were apparent only in a few sites in the first years and were removed with training on standard methods and accumulation of equipment, e.g. portable energy meters. Later, it was observed that if IT systems were not able to provide data then staff used available meters. It is possible that technology related barriers once removed are less likely to reappear as changes in process or people will not change the availability of equipment purchased. ‘Equipment’ is therefore established as an intervention to enable energy efficiency projects.

Secondly, the IT systems related tool barriers of *form of information* and *incomplete information* existed across most sites in the first year but not thereafter because of new standard reporting. This included information accessible from installed meters. Existing IT systems were used and no new system was deployed. As before, the IT systems barriers were removed with ‘hard’ changes that once changed did not reappear. This contrasts with the ‘soft’ changes related to people barriers. The enabling intervention can be generically referred to as ‘data provision’.

*D. Managerial implications*

Table 8 assembles the enablers established above. The barriers from earlier tables that were evident are aligned to the enablers from the above discussion. The enablers act as an action plan to sustain success and counter anticipated barriers. The interventions extend the initial Plant A enablers of targets, methodology and supporting organization.

Table 8. Enabling interventions to counter potential organizational barriers to energy efficiency improvements

|  |  |  |
| --- | --- | --- |
| **Enabler to sustain energy efficiency improvements** | **Primary barrier addressed** | **Primary barrier category** |
| **Vision** of organization to create the overall direction and motivate staff to engage | Urgency | Process |
| **Objectives and targets** for alignment to strategy and create urgency. They are time-bound, use common definition, assigned responsibility and regularly reported (outcome to target). Metrics are at board and operational level. | PriorityPrincipal-agentSplit incentives | Process |
| **Operational responsibility** to align board level to operational level | Accountability | Process |
| **Methods** for routines and standards | Selection | Process |
| **Training** to develop knowledge, skills and competence | TrainingBounded rationalityKnowledge | People |
| **People** (individuals) to lead and implement change within operations  | Resourcing | People |
| **Community** to transfer standard methods and routines. Champions are guided by operational responsibility to maintain engagement locally | (Many) | People |
| **Equipment** to support data collection and use of standard methods | CapitalEquipment | Tools |
| **Data provision** to support use of standard methods and routines | Form of informationIncomplete information | Tools |

This leads to the adaptation Davies’ [8] work used to create Figure 1. The enablers to sustain resource efficiency interventions have been mapped to the earlier interactions graphically in Figure 2. As before, the links present dominant connections and weaker links are not shown. The tools enablers have been included to the left.

There was acceptance that the energy efficiency approach aligned to the business objectives of both cost reduction and development of environmental responsibility. This supports the principles of the work of Zack [65] and the accounts of Drew et al. [11] of the rewards of organizational alignment with business strategy. In the earlier discussion on targets, the strategic vision of the company can be difficult to relate to at an operations level; energy efficiency was described as part of the global vision but the strategy for that aspect is led by the function which can have the biggest impact on the objective which means alignment takes time to develop. Where there is a delayed link between operations and strategy, an arrangement is needed for staff to engage without direct alignment to the corporate strategy. It was notable that local adaptation was absent here but the inclusion of tools is new.



Figure 2. Framework of enablers and barriers to sustain energy efficiency improvements

Longitudinally, there was indication of learning in year one given the removal of technology and systems barriers as well as some people barriers, e.g. lack of knowledge. Overall least progress was made in process barriers of prioritization and incentives and people barriers of urgency and resourcing. These are related. Whilst sites made progress, the lack of strategic to operational energy metrics meant prioritization and resourcing were weak, hence urgency and incentives were weak. That said, the network consistently reported significant savings.

The role of the network to communicate vertically (such as reporting of savings) and horizontally (as a community of practice) serves also to counter the misalignment of operations and strategy. Additionally, it was used to reach outwards to draw practice from other companies. This supports Cummings [7] that teams learn quickly from external sources including managerial ties [66] and adopt routines from other plants through the interaction [2] rather than the transfer [61] of people. The community enabler relates to many barriers whereas the other enablers relate to specific barriers. Perhaps because much of the case study literature focuses on single plants, the role of networks and communities has not been uncovered in resource efficiency research.

Practically, this work contributes by providing interventions that companies can use to sustain environmental efficiency programs in manufacturing operations. It provides guidance for engineering managers on how to extend lean production thinking rather than lean tools alone. This work contributes new organizational enablers, such as the need for central funding, transitional arrangements for strategy alignment and the need for a community of improvement champions. The value of the enablers is that they focus on *how* to improve resource, especially energy, efficiency to complement existing work on *what* to improve or *what* tools to use.

Little literature links maintenance to energy efficiency. Most energy efficiency initiatives originate from the central energy management role or the production improvement teams. Garetti & Taisch [15] and Tousley [58] bring out the contribution that maintenance can make in energy but examples are few. Maintenance has the technical understanding of the production processes and the more general routines/procedures for enacting change. Given that few works link the activities of maintenance to initiatives to reduce energy or wider resource consumption, then the area of practices, barriers and enablers for maintenance-driven energy reduction presents opportunities for future research. The value of embedding energy efficiency in the everyday practices in a service function compared to an operations or performance improvement function offers potential for further investigation.

VII. Conclusions

There is a growing understanding of what barriers could impede the adoption of industrial energy efficiency practice; however, what can enable such practice is less well understood. The work of lean, resource efficiency and organizational learning can inform progress in this area but there is a gap in what interventions can enable energy efficiency in manufacturing operations. Accordingly, this research sought to ascertain *the enablers for manufacturing operations to sustain energy efficiency advance*. This research contributes to knowledge by uncovering enablers and associated barriers for sustaining energy efficiency approaches to deliver environmental and cost benefit.

To counter barriers to progress, nine enablers were uncovered: Creation of vision; objectives and targets for alignment with strategy and to create urgency; operational responsibility; methods for routines and standards; training to develop competence; people to lead and implement change; a community of champions who share practice; equipment to obtain data; tools to provide data for analysis. These capture the financial investment to support improvement projects as well as measure the cost and resource improvements achieved. The enablers share many of the traits of classic lean production as well as promote organizational learning and move the emphasis from technical to adoption.

The work here contributes to organizational learning theory to cover sustaining resource efficiency; to date the operational aspects have not been addressed nor have the associated resource efficiency barriers. The originality centers on establishing enablers to energy efficiency in the context of resource efficiency programs in manufacturing operations without assuming that generic methods can be adopted directly. The longitudinal, multi-site analysis permits confidence in the identification of barriers and enablers to overcome them. The need for training or objective setting or standard methods (routines) or a supporting infrastructure may not be considered as novel responses given the volume of organizational and lean work. However, such needs have not been empirically established for resource efficiency which focused on technical rather than organizational developments. For organizational learning, the work contributes to how to sustain resource efficiency activity and respond to barriers that may arise. From a practice perspective, the enablers are tangible interventions for energy efficiency programs. The work contributes to how to sustain resource efficiency to complement what resource efficiency actions to take.

It is recognized that the research has limitations that serve to direct future research. Firstly, work was carried out within Europe, in one industrial sector and in one multi-site company. Further work is required to establish whether the enablers are complete to account for other companies in the same sector and other sectors. Secondly, organizations at different stages of maturity of energy efficiency adoption than the case company here could display different barriers and research is needed to uncover if the same enablers are effective. Thirdly, insights within the work showed manufacturing maintenance has a role in embedding learning and sustaining activity, however, insufficient literature on other companies is available for comparison. Uncovering a means by which practice could be readily adopted and sustained could be interesting research for accelerating industry-wide adoption of energy efficiency. Fourthly, there is a need to ascertain if these findings on energy can be generalized to broader resource efficiency. Finally, the role of the network in promoting activity and supporting champions did not consider the sequencing or inter-connectedness of the enablers and research here could uncover pre-requisites for any interventions.

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