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Cleaner Production in small companies: Proposal of a management methodology

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A B S T R A C T

Global level agreements related to sustainability have changed the way organisations work. Many companies, mainly the larger ones, have assessed their environmental impacts to achieve both economic and environmental benefits by reducing waste generation and by using less energy, water, and materials. Considering this approach, many of these companies have strategically set up environmental management practices guided by Cleaner Production (CP) concepts. Despite its benefits, CP has a low application rate in small and medium-sized enterprises (SMEs), which is attributed to barriers such as a lack of resources, concentrated decision-making by owners and lack of leadership. Based on CP concepts and focusing on overcoming internal barriers in SMEs, this article proposes a management methodology of CP in small companies. A longitudinal action research of six cycles was carried out to develop a suitable methodology, comprising a meta phase and a five-step cyclic phase, which was a simple and viable way of conducting a CP program. It was found that promotion and monitoring actions, prioritisation of preventive opportunities and employee involvement facilitate the process of continuous improvement. This methodology may facilitate SME environmental management and contribute to developing products and processes towards sustainability objectives more efficiently.

1. Introduction

Cleaner Production (CP) emerged as a “waste generation prevention” approach in the 1980s in contrast to the “command and control pollution treatment” approach promulgated by environmental regulations in the 1970s. CP was developed by the industry in response to end-of-pipe technology (Dieleman, 2007; Khalili et al., 2015) and can guide companies' environmental management systems, contributing to competitive advantage and improving environmental and organisational performance, as it usually results in economic benefits and a reduction of environmental impacts (Stone, 2006a). Savings are obtained by using less energy, water and materials, and waste generation reduction through complementary preventive techniques, including housekeeping and better process control, replacement of inputs, change in products and/or technologies, equipment and/or technological modifications, by-product production and recycling (Van Berkel, 2010). Almeida et al. (2015) add that CP can reduce the negative impacts of industry on human health and contributes to accelerating the transition to equitable and sustainable societies.

In 1992, the United Nations Conference on Environment and Development requested the international community to support developing countries in CP implementation (Luken and Navratil, 2004). Following this request, the World Summit on Sustainable Development implementation plan (United Nations, 2002) recommended increasing investments in CP and eco-efficiency paying special attention to small and medium-sized enterprises (SMEs) by means of incentives, support schemes and regulatory, financial and legal frameworks. Responding to these requests, efforts and investments have been made to promote CP in SMEs at a global level (Luken and Navratil, 2004; Luken et al., 2015; Van Berkel, 2010); at a regional level (Gallup and Marcotte, 2004); and at the company's supply chain level (Van Hoof and Lyon, 2013).

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Although several CP dissemination efforts focused on SMEs, generally only large companies achieved success in applying CP concepts while SMEs reported barriers, such as concentrated decision-making by owners, a lack of in-house monitoring and maintenance systems (Khalili et al., 2015), limited use of systematic techniques and tools (Silva et al., 2013); lack of enforcing environmental regulations (Silvestre and Silva Neto, 2014) and high capital costs (Shi et al., 2008).

The objective of this research is to propose a CP management methodology in SMEs that facilitates both internal barriers overcoming as well as actions of waste generation reduction. To perform this study and reach this goal, a previous structure of the methodology was defined based on a review of the CP literature available and then six cycles of action research were carried out during five years in a small metallurgical industry for previous structure application and improvement and so to define the proposed CP management methodology in SME.

2. Literature review

2.1. Cleaner Production

The United Nations Environment Programme (UNEP) states that “Cleaner Production is the continuous application of an integrated preventive environmental strategy to processes, products and services, to increase efficiency and reduce risks to humans and the environment”. Efficiency increase and environmental improvement are related to a waste generation reduction and the use of less energy, water, and materials needed for production. CP can be achieved by adopting complementary preventive techniques and practices, including changes in products, processes and equipment, housekeeping and more efficient technologies (Van Berkel, 2010).

The CP program implementation methodologies originated in the companies 3M and DuPont (Dieleman, 2007). 3M has maintained the Pollution Prevention Pays program (3P) since 1975 and its success is attributed to five factors (Van Berkel, 2000): top management support; involvement of all workers; simplicity, with ideas written on one page forms; reward system; and internal and external promotion. DuPont created a manual to encourage its managers to work towards pollution prevention and, in 1988 the USEPA published this text under the title “Waste Minimisation Opportunity Assessment Manual”. In 1989, the PRISMA project tested the USEPA methodology and developed procedures to facilitate industry and consultants using the 3P program approach (Dieleman, 2007). The UNEP applied PRISMA project methodology in some DESIRE (Demonstrations in Small Industries for Reducing Waste) projects (Van Berkel, 2004). Based on this experience, UNEP DTIE (2004) has recommended a methodology for National Cleaner Production Centres (NCPCs) consultancy services based on a sequence of five phases.

The CP program is a long-term process and besides changes in products and processes, it requires organisational attitude change (Vieira and Amaral, 2016). Stone (2006a) revealed CP programs limitations in achieving senior managers' commitment and continuous improvement, and Stone (2006b) revealed CP programs limitation as organisational change agent related to leadership, support, communication and staff involvement. Using these findings and the Theory of Organisations, Stone (2006b) proposed a CP program structure that searches for compatible design between companies' needs and culture, as well as a reflexive and iterative learning cycle.

Khan's (2008) methodology uses CP concepts to achieve the ISO14001:2004 certification. This methodology begins by obtaining top management commitment and indication of a CP champion. Then, the CP team is defined to review organisation, economic and environmental activities. This step aims to identify CP opportunities and then implement the most promising ones in terms of cost reduction or environmental performance.

Silva et al. (2013) propose a methodology enhanced by the integration of quality tools to overcome barriers to maintain and implement CP programs. Twelve phases were selected by applying the criteria of frequency, similarity and complementarity of phases mentioned in nine academic and practitioners' methodologies.

Metallurgical sector SMEs were the focus of a systematic review performed by Oliveira Neto et al. (2017) and the proposal for overcoming barriers in CP implementation in SME is a framework comprising four steps:

1. Identifying the barriers by interviewing SME managers
2. Identifying and prioritising the causes and effects of barriers by using quality tools (Gravity- Urgency-Tendency (GUT) and the Ishikawa diagram);
3. Performing economic and environmental analysis of effects (technical solutions);
4. Analysing opportunities to overcome barriers considering Return on Investment (ROI) and Material Input per Service Unit (MIPS) analyses regarding economic gains and environmental impact.

Many CP methodologies are developed for applications by consultants and Oliveira Neto et al.'s proposition (2017) is an easy framework for this purpose. As an example, the CNTL (2007) methodology includes technical visits and data gathering and analysis. On the other hand, 3M's 3-P program (Van Berkel, 2000) and Stone's (2006b) methodologies include employee involvement as important factors for CP program success. Teamwork involving management and operational functions is a necessary CP program strategy (Vieira and Amaral, 2016; Stone, 2006a).

2.2. Barriers to Cleaner Production in small and medium-sized enterprises

There is a high variation in CP adoption among countries, due to different regulations, industrial sectors and firm sizes (Luken and Van Rompaey, 2008). However, there is a common sense that SMEs face specific barriers and that they will innovate towards sustainability differently from larger companies (Klewitz and Hansen, 2014).

Murillo-Luna et al. (2011) surveyed Spanish firms regarding their barriers to adopting proactive environmental strategies. The authors state that SMEs face greater barriers, both external and internal, than large companies in terms of adopting environmental measures. However, only internal barriers can be characterised as “effective” towards proactive environmental behaviour, which are: limited financial capabilities for environmental investment, low employee involvement in decision-making, lack of technological information and communication capabilities, aversion to innovation and deficient investment of resources in R&D.

Regarding the investments for CP implementation, in a survey conducted in China by Shi et al. (2008), the lack of economic incentive policies was the first barrier and the high cost of capital was the third barrier. In Luken and Van Rompaey's survey (2008), in nine countries, the value of investment was the first barrier. Other financial barriers are SME difficulties to obtain bank loans (Gallup and Marcotte, 2004; Luken and Navratil, 2004) and water, electricity and the low cost of waste disposal rates (Frijns and Van Vliet, 1999; Van Hoof and Lyon, 2013). Investment from SMEs occurs only when there is short-term return (Frijns and Van Vliet, 1999). Luken and Van Rompaey (2008) argue that ranking financial barriers as the main barrier is a mistake as many CP opportunities are inexpensive. Meath et al. (2016) indicate the prohibitive cost of investing (33% of respondents) as a major barrier to increasing the energy efficiency of German, Swedish and Italian SMEs. However, their research also reveals significant barriers such as the management team's lack of time (21% of respondents) and the team's lack of involvement or negative attitudes towards change (33% of respondents).

Externally to SMEs, a lack of coordination and support from local organisations indicate CP is not on the government agenda (Frijns and Van Vliet, 1999; Silvestre and Silva Neto, 2014). Internally, SMEs do not include environmental issues in their strategic planning, as there is pressure for short-term profits and accounting systems fail to capture environmental costs and benefits (Luken and Navratil, 2004). In the operational area, there is a lack of information, skill and adequate training (Luken and Navratil, 2004), as well as procedures based on tacit knowledge. Khalili et al. (2015) adds that workers are not involved in decision-making processes and there is a lack of internal monitoring and maintenance systems. In behavioural aspects, non-compliance with environmental regulation by SMEs is the main barrier to CP adoption. Other barriers included in this topic are:

- Lack of awareness of support organisations and entrepreneurial resistance to changes (Silvestre and Silva Neto, 2014);
- Underestimation of environmental problems and risk perception to implement CP improvements (Frijns and Van Vliet, 1999; UNEP DTIE, 2004);
- Top-down management prevents implementing operator suggestions (Aikenhead et al., 2015);
- Demotivation of operators for ecodesign activities (Dekoninck et al., 2016); and
- Legislations that push towards end-of-pipe techniques (Luken and Navratil, 2004).

Most companies focus on CP assessment results rather than focusing on inserting CP into everyday activities to mitigate difficulties in learning and moving towards the continuous improvement process (Dieleman, 2007; Luken and Rompaey, 2008; Stone, 2006a).

3. Materials and methods

The Brazilian Cleaner Production Centre (CNTL in Portuguese) (2007) and the Brazilian Business Council for Sustainable Development (CEBDS in Portuguese) (2003) methodologies consider the following actions to be taken sequentially: CP practices focused on waste reduction at source should be primarily implemented by means of modifications in products and processes; waste that cannot be mitigated at the source should be re-integrated into company processes by internal recycling, for example, when producing by-products; and external recycling should be adopted as a last alternative. CP actions will be more efficient the closer they are to waste generation origin. This concept has led to the inclusion of the "Generate preventive opportunity" step in the proposed methodology.

Difficulties in applying the CNTL (2007) methodology at the research unit motivated us to search for articles that contain CP strategies and methodologies in SMEs. A set of articles was selected which contained the following keywords in their title: *Cleaner Production* or *Pollution Prevention* or *waste minimisation* or *environmental management* or *small company* or *small and medium company*. The initial selection set was then reduced to the following 20 articles: Andrews et al. (2002), Baas (2007), Gallup and Marcotte (2004), Gärdströn and Norrthon (1994), Gombault and Versteege (1999), Hillary (2004), Howgrave-Graham and Van Berkel (2007), Khalili et al. (2015), Luken and Navratil (2004), Ortolano et al. (2014), Shi et al. (2008), Silva et al. (2013), Silvestre and Silva Neto (2014), Stone (2006a, 2006b), Van Berkel (1994), Van Berkel (2004), Van Berkel (2011), Van Berkel and Kortman (1993), and Van Hoof and Lyon (2013). The literature review from these articles did not reveal any CP management methodology in SMEs, and therefore the following research question was formulated: How can CP actions be structured in SMEs? As an initial answer, Table 1 presents a previous CP management methodology in SMEs based on the PDCA cycle (Silva et al., 2013) and the literature review.

This previous structure served as an initial CP management methodology in SME. The author (a), who has 31 years of experience as an industrial engineer/manager in 5 companies, carried out six action research (AR) cycles over a five-year period, guided by a CP methodology literature review.

This research was carried out at a multinational metallurgical company, which has 28 employees located in São Paulo state, Brazil. The company produces on average 38-tons per month of cable tray and its accessories for electric installation infrastructures.

The AR method joins organisation representatives and scholars in a process characterised by cooperation, democratic will, and information and knowledge sharing (Thiollent, 2011), and the objective is to construct scientific knowledge through a problem-solving approach (Coughlan and Coghlan, 2002).

Data collection was done by using a participant observer technique (Flynn et al., 1990) in brainstorming sessions (UNEP DTIE, 2004) to define root causes of waste generation by using the "5 Whys" method (Ohno, 1988) and to generate CP improvement opportunities.

4. Results and discussion

This section presents the development and study of six action research cycles (ARC) over a period of 5 years. These ARCs emerged from analysing waste generation indicators or through ideas generated in brainstorming sessions. Each ARC provided CP management practice and conclusions that led to the proposition of CP management methodology in SMEs. The results and analyses of each ARC are described next.

4.1. Sale of guillotined cutting process residue (1st ARC)

This ARC stemmed from the following brainstorming question: what can be done with guillotined cutting residue (GCR) besides selling them as scrap? The alternatives selected were: sell to metallurgic stamping enterprise or internal production of small items for electrical installations. Initially, the strategy of GCR selling was chosen, but after several offers there was no sale. Potential purchasers reported GCR was not suitable for machine feeding systems and freight cost was unfeasible. After offering GCR to a company, this company offered to sell its own GCR. It was observed that this proposal was feasible to produce cable tray accessories. This CP practice reduced steel plate consumption by 6.6 ton/year and saved US$ 3488.99/year.

Data analysis from this ARC led to the following conclusion:

1 This ARC did not evolve and it is classified as external recycling according to CNTL (2007) and CEBDS (2003) prioritisation criterion;

4.2. Production of small items (2nd ARC)

Part of the GCR was regularly sent to the service provider for manufacturing small items used for electrical installations. The

Table 1
CP management methodology in SMEs: previous structure based on the PDCA cycle and the literature review.

PDCA phase	Methodology step	Description
Plan	- Plan	Define production flow, objectives, when and how analysis will be performed.
Do	- Analyse flows - Generate preventative ideas	People analyse production flows, come up with ideas, propose and prioritise CP improvements.
Check	- Monitor - Approve technically - Approve environmentally - Approve economically	Indicator monitoring of continuous improvement process; Technical approval with involvement of operational level; Verification of environmental and economic viability.
Act	- Implement change - Continuously improve	Operational level implements approved ideas and people promote continuous improvement in CP opportunity implementation process.

objective of the ARC was to increase the consumption of GCR. The proposal was to increase the volume of sales of small items by reducing costs that would be obtained by transferring external production to internal production. The brainstorming session defined a project of a new machine and tools. Project economic analysis resulted in a negative net present value of US$ 9709.57 and of a 4.5-year payback. The project was not feasible and the reasons were the high cost of capital and the low market price of small items.

In another brainstorming session, the following question was asked: what can be done to use GCR internally without investment? The generated proposal was to produce most of the small item volume with existing machines and adapted tools. Production tests confirmed technical feasibility with no investments and therefore, internal production was established. The cost of small items was reduced, however the sales volume remained the same and there was no increase in GCR consumption.

Data analysis from this ARC led to the following conclusions:

1 This ARC evolved very slowly and it is classified as internal recycling according to CNTL (2007) and CEBDS (2003) prioritisation criterion;

4.3. Product design modification (3rd ARC)

Following CP prevention concepts, the analysis of this ARC began by adopting the “5 Whys” technique as presented in Table 2. The table division into two sets is due to different responses to the initial question.

In the brainstorming session, the following question was asked: how could product design be changed to mitigate plate waste? The ideas were: 1st - analyse the competitors' product brochure; 2nd - analyse manufacturers' product brochures from overseas; 3rd - use of company's matrix design concept. Work team supported third idea. Fig. 1 compares Brazilian traditional design and new design.

The new design definition followed the methodology proposed in Table 1. In the Approval step, accessory samples were produced and quickly approved by operators and sellers, then by the general manager and by the customers. Analysis showed a reduction of 17.1-ton/year in plate waste generation, a reduction of 15.2-ton/year of hot dip galvanization, savings of US$ 32,456.05/year and an investment of US$ 239.36 to purchase a tool. The project was approved and implementation occurred quickly. Operators suggested modifications as items were produced and this provided continuous improvement in new designs.

Data analysis from this ARC led to the following conclusions:

1 This ARC evolved quickly and it is classified as a reduction at the source according to CNTL (2007) and CEBDS (2003);
2 “5 Whys” indicated that the plate waste generation root cause in this ARC was the use of market traditional design without researching design concept alternatives;
3 The operators contributed to generating CP preventive opportunities, CP improvement implementation, and continuous improvement process of the new design drawings;
4 Steps carried out: Planning, Flow analysis, idea generation, operators and sellers' approval, top management approval, customers' approval and implementation.

4.4. Accessory production method modification (4th ARC)

Guided by the second set of questions and answers from Table 2, a new Planning stage was carried out to analyse accessory production methods. Production supervisor and draftsman were in charge of Flow analysis and the “Generate preventive opportunities” stage and they found that fitting trapezoidal shapes, as indicated in Fig. 2 (dark grey represents residue) reduces plate

Table 2
“5 Whys” question and answer sets for 3rd action research cycle (product design modification).

1st set: (Q1- question 1; A1 - answer 1)	Q1: Why do we have plate waste at production? A1: Accessory drawing causes waste; Q2: Why does accessory drawing cause waste? A2: Accessory drawing has inclined cutting; Q3: Why does accessory drawing have inclined cutting? A3: Product design is this way; Q4: Why product design is this way? A4: Product design was copied from other Brazilian manufacturers; Q5: Why was product design copied from other Brazilian manufacturers? A5: We do not know, we think it was option chosen when production began.
2nd set:	Q1: Why do we have plate waste at production? A1: In production, first we cut rectangles and then cut at an angle; Q2: Why do we first cut rectangles and then cut them at an angle? A2: We always did this and the drawing was done following this idea; Q3: Why did we always do it this way? A3: We do not know; it has not yet been thought about in a different way.

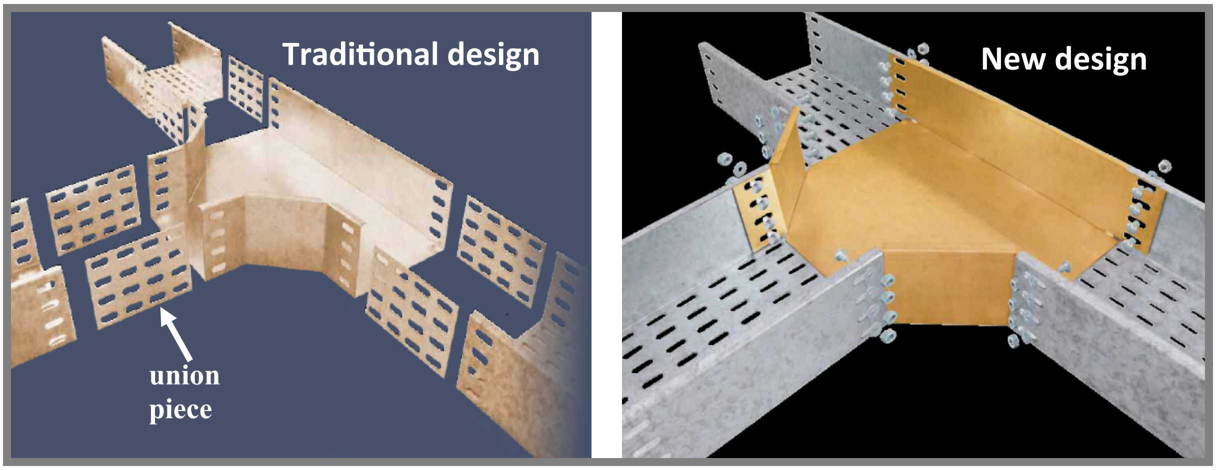

Fig. 1. Cable tray 'T' accessory - Brazilian traditional design versus new design.

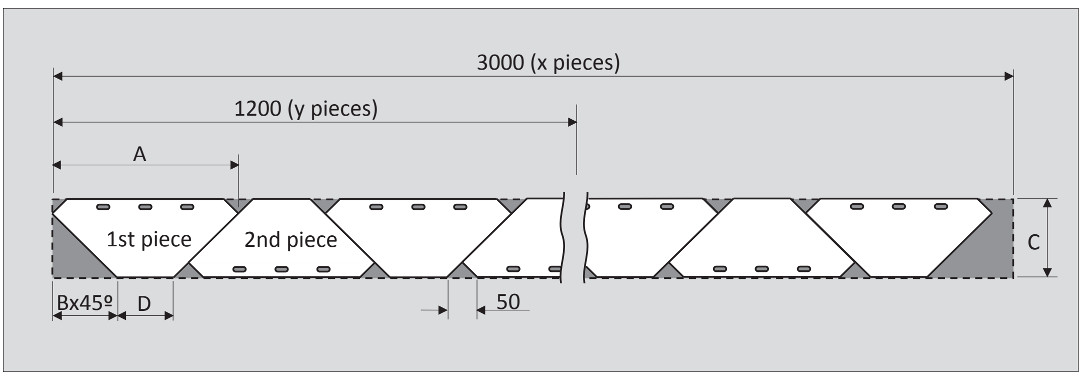

Fig. 2. New production method drawing, enabling reduction of plate waste on accessories production.

waste. This new production method became a reference.

The operators approved new methods as they reduced plate waste. Analysis showed a 3.8-ton/year reduction in scrap generation and savings of US$ 4781.88/year. Despite approval, it was observed that operators used old methods in manufacturing. Awareness-raising meetings were held to discuss the advantages, but this action was not effective. Operators were resistant to modifications in the method and reported that the new method was more difficult and slower. An agreement was established: production time would not be monitored until new methods were learned and standardised. In order to promote the method changes, brainstorming sessions were carried out questioning how to facilitate the use of the new method. As a consequence, new production methods were established slowly.

Data analysis from this ARC led to the following conclusions:

1 According to CNTL (2007) and CEBDS (2003), this ARC is classified as "reduction at source", however it evolved slowly due to operators' resistance to modifications;
2 Non-involvement of operator in the stage of idea generation may cause operators resistance to modifications;
3 Employee non-involvement barrier in the decision-making process to changes was observed. Murillo-Luna et al. (2011) also reported low employee involvement in decision-making in their research. Promoting and monitoring of changes were carried out until the desired standard was reached;
4 Preventive action led to eliminating the tacit knowledge, a barrier reported by Luken and Navratil (2004), when defining the production method. In the new strategy, the work team analyses the waste to define new production methods and registration of drawings for production standardisation;
5 Steps carried out: Planning, Flow analysis, Generation of preventive opportunities (idea generation), operators' approval, Implementation, Standardisation, and Promoting and Monitoring.

4.5. Plate cutting plan (5th ARC)

Daily monitoring and scrap indicator analysis showed high level of plate waste generation in 3-m length strips. This finding led to devising the steps in Table 1. The work team analysed plate cutting production flow. The "5 Whys" set shown in Table 3 shows the cutting strategy established tacitly by operators and data from 20 production orders indicated 4.51% of scrap in this strategy.

Table 3
"5 Whys" question and answer sets for 5th action research (plate cutting plan).

(Q1- question 1; A1 - answer 1)
Q1: Why do we have waste generation in strips of 3 m in length when guillotining plates?
A1: In each order, we first cut pieces of greater widths; then with the leftovers, we cut smaller pieces; in the end, we have plate waste.
Q2: Why do we first cut pieces of greater widths in each order?
A2: Cutting the smaller pieces first results in more waste at the end.
Q3: Why does cutting the smaller width pieces first result in more waste at the end?
A3: We tested it sometimes and it results in more waste.

The brainstorming session was organised questioning how waste in 3-m strips can be reduced at guillotined plate cutting. There were only suggestions to consult service suppliers and plate suppliers to verify their cutting strategy. It was observed that service suppliers had a similar strategy and plate suppliers have a different strategy. The analysis of the plate supplier's strategy led to CP opportunity generation and defining a new strategy (called “cut plan”) to cut plates that combine pieces of different widths in order to maximise the use of plate. In order to reduce the amount of waste, some pieces are cut beyond what is needed and are stored for future use. This strategy allows for a reduction of 3-m strips waste to 0.29%.

A meeting was organised with the operational team to present the cut plan strategy. Operators tested and approved this strategy. Implementation was very fast and operators presented suggestions for improvements and established a new standard method for plate cutting. A reduction of 4% can be inferred at plate waste generation, which is equivalent to 13.4-ton/year of waste reduction and savings of US$ 16,688.72/year.

Data analysis from this ARC led to the following conclusions:

1 This ARC evolved quickly and it is classified as “reduction at source” according to CNTL (2007) and CEBDS (2003);
2 Operational team participated in the decision-making process, overcoming the barrier mentioned by Meath et al. (2016), and carried out cutting method improvements and standardisation;
3 The root cause of waste in 3-m strips is a lack of engineering planning for the guillotine cutting process. This indicates that flow analysis should go beyond production and analyse the engineering flows at SMEs to eliminate the use of tacit knowledge;
4 The new proposals were implemented and monitored until it reached the desired standard. There were no barriers and implementation was quick, revealing that promoting and monitoring modifications can contribute to changing effectiveness in a continuous improvement process;
5 Steps carried out: Planning, Flow analysis, Generation of preventive opportunities, operators' approval, Implementation, Standardisation, and Promoting and Monitoring.

4.6. Plate perforation drawing (6th ARC)

Fully perforated plates are exclusive raw material for perforated cable tray. The cutting plan was not effective for this raw material and an analysis of the scrap indicator pointed out 7.42% of waste in guillotined cutting. This led to devising the steps in Table 1 for new improvements.

The “5 Whys” technique and work team brainstorming generated the following idea: firstly, cut plate in strips and then perforation of strips. The perforation service supplier was consulted and contributed with the idea illustrated in Fig. 3, where each perforated band corresponds to a cable tray and unperforated band can be used to produce accessories.

Perforation drawing specifications were tested and validated by operators. The steps of Implementation and Standardisation of new production methods were promoted and monitored and these steps were easy and quick. This CP practice eliminated waste in the guillotined cut of perforated plates. There was a reduction of 4.2-ton/year in steel mass and an equivalent saving of US$ 5260.51/year.

Data analysis from this ARC led to the following conclusions:

1 This ARC evolved quickly and it is classified as “reduction at source” according to CNTL (2007) and CEBDS (2003);
2 Operational team participated in decision-making processes, implemented and improved methods of cutting perforated plates. New methods were promoted and monitored until it achieved the desired standard;
3 The root cause for waste of perforated plate is the lack of a specification that considers the reduction of waste generation. This reinforces that flow analysis must go beyond production and analysing engineering flows in SMEs.
4 Steps carried out: Planning, Flow analysis, Generation of preventive opportunities, operators' approval, Implementation, Standardisation, and Promoting and Monitoring.

4.7. Performance indicator – percentage (%) of scrap

The percentage of scrap was adopted as a suitable performance indicator to check CP new practices evolution and analyse new potential improvements in this research. Fig. 4 shows the percentage of scrap at each quarter during a 5-year AR period.

Tendency line shows the reduction of scrap over time and it suggests the continuous improvement process establishment. This reinforces effectiveness of the following approaches used in ARC:

- Involvement of operational team in the root cause definition and analysis, CP opportunity generation, improvement idea approval and CP improvement implementation;

Fig. 3. Plate perforation specification drawing provides waste reduction of raw material.

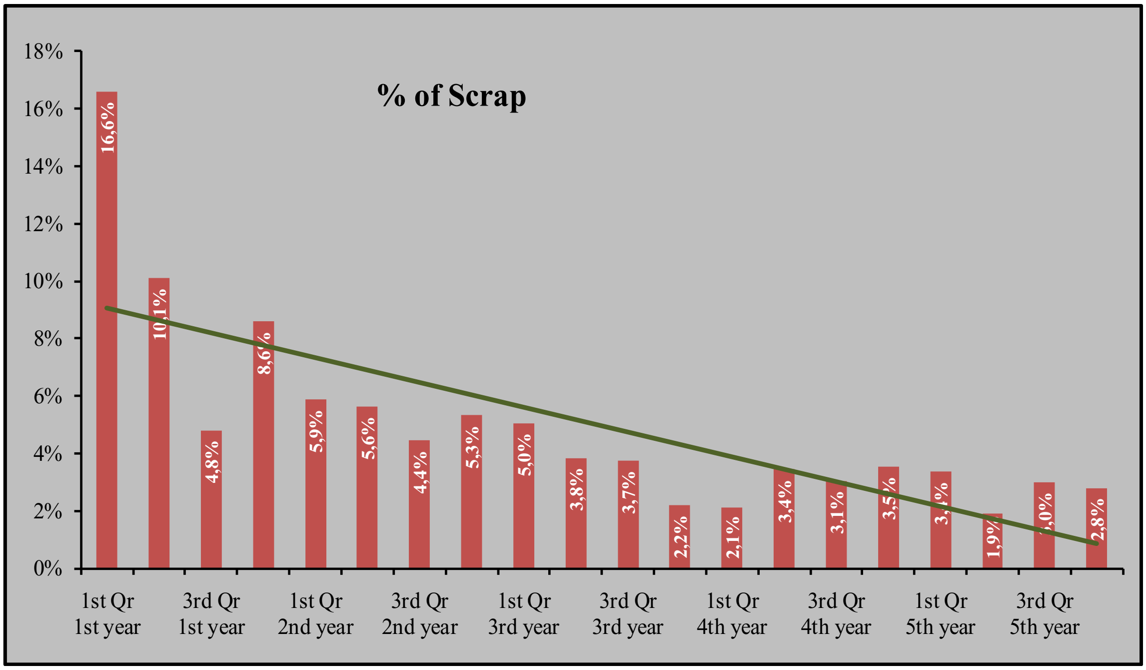

Fig. 4. Evolution of percentage of scrap indicator over a 5-year period (Note: 1st Qr means first quarter).

- Actions to promote and monitor modifications to start a new cycle round to overcome barriers and to reach desired CP improvement standards;
- Applying the prioritisation criterion (CNTL, 2007; CBEDS, 2003): first CP practices of reduction at source and then CP practices of reutilisation and external recycling as the last alternative. Application of CP practices will be more efficient the closer to the waste generation origin.

4.8. Proposition of a Cleaner Production management methodology for small companies

Sections 4.1 to 4.7 discussed methodological steps in CP practices application and indicated adjustment points at previous structure (Table 1) of the CP management methodology for SMEs. Table 4 lists these adjustment points.

Based upon these adjustment points and methodological steps which occurred in ARCs, Fig. 5 shows schematically the dynamic of CP management methodology proposed for SMEs.

The proposed methodology consists of a 'Promoting and Monitoring' meta phase and a 5-step cyclical phase to generate preventive opportunities and prioritise those with lower investment and which are easier to make CP improvements in SMEs. The meta phase can perform actions in any of the five cyclical phases and should focus on ensuring the continuous improvement process by promoting and monitoring CP improvements.

Table 5 details each step objectives of the proposed methodology.

The proposed methodology is designed to be used by SME operational team and managers. However, almost all methodologies studied in this article are for consultancy purposes. Stone's (2006b) methodology shows general guidelines and it may be customised to be applied by SME operational team and managers, although it requires effort in terms of research and project implementation. The novelty of this research is to provide a different methodology for cleaner production management, whose steps and phases differ from other methodologies mainly in two aspects: Promote and Monitoring meta phase; and standardisation actions (from the Standardise and Planning step) that are unique among methodologies studied.

Silva et al. (2013) highlight quality tools to overcome the CP program implementation barriers. Aligned to Stone's (2006b) methodology and the 3M's 3-P program (Van Berkel, 2000), the proposed methodology includes employee involvement as a crucial factor for CP program success. Aligned with Dieleman (2007),

Table 4
Adjustment points at previous structure of the CP management methodology in SMEs.

Adjustment point	Description
Standardisation	Standardisation of new procedures, drawings and production methods should be reached. The cycle should have new rounds with new actions until the desired standard is achieved.
Promotion and Monitoring	Actions to promote and monitor modification should be performed until desired standard is achieved. A manager should be assigned to promote and monitor modification, ensure involvement of the operational level in flow analysis, generation of opportunities, approval and implementation of improvement.
Approval process	Any and all modifications should be approved first at an operational level (operators, draftsman), and then if necessary by the sales department, top management and customers.
Prioritisation of changes	Priority should be given to easier modifications that are possible to implement with available resources and at the same time prioritise smaller investment modifications;
Departments for flow analysis	Flow analysis should occur at production, including suppliers, and especially at engineering department/areas of definition of drawings, process, and specifications.

Fig. 5. Proposal of the Cleaner Production management methodology in small companies.

Luken and Rompaey (2008), Stone (2006a, 2006b) and Vieira and Amaral (2016), the proposed methodology attempts to insert CP into everyday activities and move towards the continuous improvement process. To achieve both people involvement and continuous improvement, the Promotion and Monitoring meta phase was designed.

Standardisation actions are also related to continuous improvement, as they start new rounds of the cyclic phase if modified processes did not achieve desired patterns. Standardisation can also avoid tacit knowledge barriers pointed out by Luken and Navratil (2004) and resistance to change shown by UNEP DTIE (2004).

Planning actions from the proposed methodology define flows to be analysed and their goals, which are not clear in the methodologies studied. Similar to Meath et al. (2016) and Murillo-Luna et al. (2011) studies, in this research employee non-involvement was observed in the decision-making process when process modifications were necessary. Then, the “Analyse flow” step was designed to adopt the people involvement strategy and to avoid this barrier. The “Generate preventive opportunities” step was designed based on the CNTL (2007) methodology and its prioritisation criterion. The “Get approval” step was designed to use a bottom-up approach to avoid non-implementation barriers of operators' suggestions (Aikenhead et al., 2015) and employee non-involvement in decision-making processes (Khalili et al., 2015). The “Get approval” step was also designed to prioritise CP practices of less investment and less difficult to implement in order to avoid the economic barriers pointed out by Frijns and Van Vliet (1999), Gallup and Marcotte (2004), Luken and Navratil (2004), Luken and Van Rompaey (2008), Meath et al. (2016), Murillo-Luna et al. (2011), Shi et al. (2008) and Van Hoof and Lyon (2013).

Table 6 presents a summary of the practical applications of the proposed methodology.

Procedures and actions in meta phase should be the responsibility of a person (owner or industrial manager) skilled in people involvement and with decision-making power in manufacturing processes, engineering and materials and services purchasing.

5. Conclusions

The novelty of this paper is to propose a methodology to manage CP in SMEs, which was based on data analysis of six action research cycles and a previous structure developed with literature review support. The proposed methodology is formed by a ‘Promoting and Monitoring’ meta phase and a 5-step cyclic phase formed by actions: ‘Standardise and Plan’, ‘Analyse flow’, ‘Generate preventive opportunities’, ‘Get approval’ and ‘Implement CP improvement’. This proposal aims to simplify and encourage actions in overcoming the internal barriers to CP implementation and continuous improvement.

The proposed methodology presented a good performance when applied to a small metallurgy company. In five years, there was roughly 70% reduction in waste generation. Implemented CP practices improved working conditions, reduced scrap generation by 38.5-ton/year, an equivalent economy of US$ 62,676.15/year, with an investment of US$ 239.36. However, the most relevant result was establishing the continuous improvement process that supports the following conclusions. The promotion and monitoring actions are effective in terms of involving the operational team in defining the root cause of the waste, generating preventive opportunities, approving, implementing and standardising the improvements. The non-involvement of employees in these steps can restrict continuous improvement speed. The prioritisation criterion of adopting primarily ‘reduction at source’ and, in sequence, ‘internal reuse’ and ‘external recycling’ as last alternative is efficient and effective. The definition of the root cause by applying the “5 Whys” technique and the generation of preventive opportunities in the brainstorming sessions are appropriate techniques for the proposed methodology. This methodology can reduce non-formalised procedures and the use of tacit knowledge. Main waste generation root causes were found in engineering as there were no appropriate specifications for production process (methods drawing, cutting plans, perforation services drawing) to mitigate use of tacit knowledge.

Data collection from just one company is the main limitation of

Table 5
Objectives of the proposed methodology meta phase and steps.

Meta phase/Step	Objectives
Promoting and Monitoring	Promote the continuous improvement process; Promote and monitor actions of overcoming barriers to CP until standard is obtained; Involve people from operational level in decision-making process at product and process changes.
Standardise and Planning	Definition of which flow will be analysed and its goals; Beginning of new rounds of cyclic phase to seek patterns of processes and methods affected by improvements.
Analyse flow	Identify root cause of waste generation; Work team with those involved in flows; Increase CP awareness and knowledge.
Generate preventive opportunities	Identify CP improvements and prioritise CP practices of reduction at source; Team work with those involved in flows.
Get approval	Involve people in approval starting by operational level; Checking technical, environmental and economic viability; Prioritise strategies of less investment and less difficulty of implementation; Overcome the lack of resources.
Implement CP improvement	Involve operational team at necessary process changes; Promote and initiate continuous improvements to obtain standards; Overcome barriers of lack of commitment, information and communication.

Table 6
Summary of practical applications of the proposed CP management methodology in SME.

Steps	Cyclic phase procedure	Meta phase procedure
Standardise and Planning	1. Standardisation of procedures and methods among operators; 2. Run five-step cycle until waste reduction is achieved; 3. Review drawings and methods affected by previous improvement; 4. Define new flow to be analysed; 5. Define environmental, economic and work conditions improvement goals.	1. Visually monitor production run according to new standard; 2. Promote new method training so that everyone can follow it; 3. Tell team about new flow analysis; 4. Talk to people informally to obtain improvement suggestions; 5. Consider organisation values, policies, and available resources.
Analyse flow	6. Investigate waste origin. Consider engineering flows; 7. Record location and quantity of each waste generated; 8. Identify waste generation cause.	6. Involve team in decision process to choose flow to be analysed; 7. Define: when, who, how and resources to carry out flow analysis; 8. Define use of simple resources.
Generate preventive opportunities	9. Generate opportunities that prevent waste generation; 10. Prioritise waste generation reduction at source.	9. Involve team in generating ideas. Meetings, brainstorming, etc.; 10. Insert mechanisms to generate opportunities for improvements; 11. Register all suggested improvement opportunities.
Get approval	11. Prioritise lower investment improvements and easier to implement; 12. Check implementation technical, environmental and economic viability; 13. Include all, including the simplest improvements, in approval process.	12. Involve all levels at approval, starting by operational level; 13. Disseminate CP improvement opportunities in the search for approval.
Implement CP improvements	14. Implement approved improvements.	14. Involve operational level in improvement implementation; 15. Record dates, monitor and set deadlines for implementation; 16. Define performance indicators for long-term monitoring.

this research. It can be observed that the researchers' experience contributed to the methodology design. This article proposes a CP management methodology in SMEs that may support their sustainable development goals, therefore it is relevant that new research refines this methodology based on applications in SMEs from other segments. Longitudinal studies are recommended to observe the establishment of continuous improvement process. However, short case studies are also possible to investigate participants' opinions about using the proposed methodology.

Declarations of interest

None.

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