Guideline C-VSM

Di-Plast

Digital Circular Economy for the Plastics Industry

Prepare by:

University of Luxembourg

Jeff Mangers

José Francisco Brás Loureiro

Mahdi Amne Elahi, Ph.D.

Prof. Dr.-Ing. Peter Plapper

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List of abbreviations

Abbreviation	Term
BOL	Beginning-of-Life
CE	Circular Economy
C-VSM	Circular Value Stream Management
Di-Plast	Digital Circular Economy for the Plastics
EOL	End-of-Life
EU	European Union
fu	Functional unit
KPI	Key performance indicator
PET	Polyethylenterephthalat
PLC	Product life cycle
PPC	Production Planning and Control
rPM	recycled plastic material
SC	Supply-chain
VSM	Value Stream Map

Glossary

Circular Economy (CE) – An economic system, improving the linear approach by implementing methods to reduce, reuse, recycle and recover resources, whilst targeting sustainable growth [1]

Information flow (D- & R-) – Information flows indicating the partner's involvement in the design or recovery processes [2]

Lean – A customer-centric production system, which uses less of everything compared to mass production by eliminating waste [3]

Micro – Main analysis level, focusing on the company-wide value creation, retention, and recovery along the value chain

Meso – Optional analysis level centered around a cross-company setting

Macro – Optional analysis level focusing on the entire supply chain

Resource flow –Flow of materials, products, or services

R-infrastructure – Regroup of all the different facilities related to a resource retake. R is a byword for the 9R-framework and is used as acronym for the different possibilities which exits (e.g., recycle, remanufacture, reuse, etc.)

Sustainability – A triparty of economic, environmental, and social aspects, regarding the needs of the current generations without neglecting the prosperity of future generations

VSM – A visual and informative map of product and information flows within organizations, helping to see the sources of waste along a value stream. Value stream mapping is one step f the overall procedure value stream management [4], [5]

Context

The concept of circular economy (CE) is gaining increasing attention as a suitable solution to deviate from the linear economy without neglecting the goals of sustainable development. Closing resource loops and keeping resources in the system at the highest level of use for as long as possible are cited as the main goals of CE. To advance the paradigm change from a linear to a CE, policy frameworks in Europe are getting stricter by specifying that all plastic packaging placed on the EU market by 2030, should be reusable or recyclable [6]. However, there are many barriers to achieving this goal, especially with interconnected process-chains. Often, individual process components, so-called bottlenecks, prevent entire process chains from being implemented effectively regarding CE. These problem areas can only be identified through a holistic CE analysis, which is where this guideline is intended to help. For companies looking for guidance to better understand their own (micro) or supply chains (macro) process chains regarding CE, the following guide provides orientation.

Di-Plast – Digital Circular Economy for the Plastics Industry, is a research initiative funded by the EU Interreg NWE program, which develops solutions for the plastics industry regarding an improved usage of recycled plastic material (rPM) through the application of digital tools, in cooperation with leading experts. Di-Plast currently pursues 4 different pilot programs. The third pilot, "Value Stream Management Pilot" (VSM), emphasizes the visualization and analysis of value chains, respectively a company's processes. The idea is to deliver value from the customer's perspective and to continuously improve the process chain by collecting and evaluating the value chain and information flow [7]. Due to the increasing interest in the circular economy (CE) by policy makers and scholars, the adoption of circularity principles alongside the implementation of a value stream is being analyzed [2].

The upcoming guideline follows the in [2] introduced ideas, as well as new concepts, and applies it to the standardized VSM tool firstly mentioned by Rother & Shook in their book "Learning to See: Value Stream Mapping to Add Value and Eliminate Muda" [5] and consequently defined under the ISO 22468 [4]. The use cases for this guide coincide with the use cases for the lean-centric version with the adoption of circularity, which targets the development of close and slow loops, as well as minimized waste and sustainable value chain [8]. The following guideline targets a broad user pool, such that any user, like either an external consultant or an internal coordinator responsible for lean can assess and evaluate any value chain from a circular perspective, whilst simultaneously pursuing a continuous improvement process.

For more information on using VSM to gather, process, and apply end-of-life (EOL)-process information to provide the beginning-of-life (BOL) with critical information about a CE-adapted product design, refer to [x].

Disclaimer:

The material and information contained in this document are to be used as guidance and not to redefine the already consolidated VSM method or to educate the practitioner on basic lean principles. The Di-Plast project team is not responsible for the consequences of the incorrect application of the content.

1. Introduction

The concept of CE is attracting more and more attention and is currently a highly debated topic within scientific, political and, industrial communities [9]. CE promotes the responsible and cyclical use of resources, the longevity of products [10], the minimization of waste, and this without neglecting sustainability. CE is seen as a way to overcome the current dominant economic development model, the so-called 'take, make and dispose', by promoting the adoption of closed and slowed resource loops [11] and thus represents the latest attempt to conceptualize the integration of economic activity and environmental wellbeing in a sustainable way [1]. However, there are several barriers and hurdles (e.g. technical, cultural, market and regulatory barriers) [12] that prevent a successful transition from a linear to a circular economy, mainly because most sectors focus on making a linear system circular rather than applying CE principles holistically. This is where this guideline comes in and describes the various steps a company can take to holistically analyze the internal and supply chain process chains for CE. This should help to better understand (learning to see) the basic principles of CE and to apply them in an industrial environment. The individual method steps are listed in sequence and accompany the companies step by step in the analysis.

The traditional Value Stream Management method is an effective tool for the collection, evaluation and continuous improvement of product and information flows within organizations [4]. The hereinafter described guideline for the so-called C-VSM is based on [4], the results from a PET-bottle case study [2], the same as on the gained insights during the Di-Plast pilot phase.

Regarding the problem statement within the Di-Plast project, the traditional method was expanded according to the needs and requirements of CE. The following guideline explains without redefining the already established lean-oriented version the different steps which are necessary to fulfil a C-VSM and guide its user through the respective process. The outcome is a value stream map of the current state of a production, or any kind of resource recovering facility and helps to better understand the internal processes. This VSM is the framework for the later analysis of improvement potentials, regarding the lean, sustainable, and CE aspects of continuous improvement.

The analysis can either be performed on one specific company (micro-level), on a cross-company setting (meso-level) to the point of a complete supply chain (macro-level). For any of the desired kind of analysis, the starting point is always the company-level, which can be further elaborated towards the other levels. This approach is methodically separated by first directing the practitioner through the essential micro-level analysis and an afterward complementary rundown of the same ideas applied on a macro level.

A basic VSM itself consists of three main blocs. The first bloc is the main resource flow, together with its respective auxiliary flows, flowing through the internal processes. The second bloc is the interchanging companies, meaning the customers and suppliers. The third element forms the needed information exchange, which is necessary to communicate internally with the responsible product designer and the responsible companies/departments for recovery.

The guideline starts by following the simple stages of the C-VSM procedure with a final assessment section. The annex contains a detailed example, a table recapitulating all the symbols as well as a list of possible indicators.

2. C-VSM procedure

The C-VSM procedure is divided into three main Stages:

1) Value Stream Analysis,
2) Value Stream Design and
3) Value Stream Planning

Each phase is sub-divided into more specific steps, visualized by Figure 1. After the selection of a representative product family, relevant data is collected regarding the current state of the value stream. Based on this current state, concepts for the identification of improvement potentials such as continuous improvement are applied, which lead to a desired future state. The individual suggestions for improvement are documented in a catalogue of measures for improvement. Subsequently, this the elaborated value stream plan is discussed with the responsible employees and implemented within the organization.

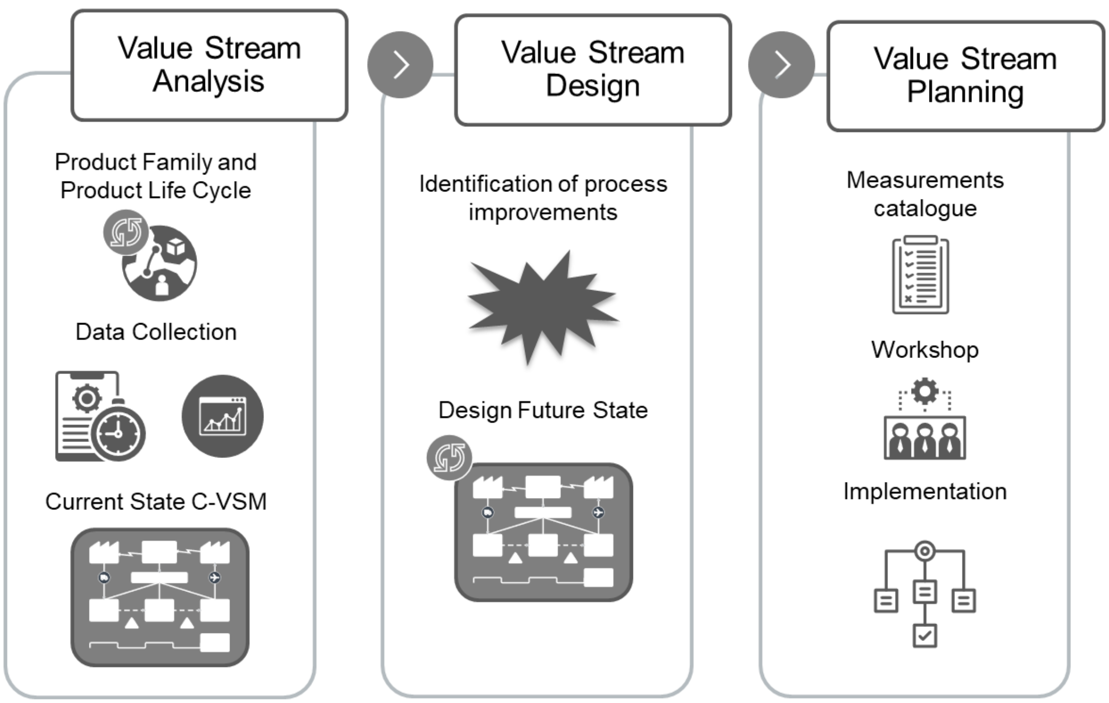


Figure 1: C-VSM procedure

The three mentioned phases should follow the PDCA (Plan-Do-Check-Act) thought, to strive for continuous improvement. More details can be found hereinafter, and a step-by-step plan can be found in the annex.

3. Value Stream Analysis

The companies' main focus should lay on their internal processes and how they can create, maintain and recover value within their production line. The first focus is on better understanding and visualizing the internal processes (micro-level), aiming to identify internal inefficiencies and thus reduce waste. After that, an optional, broader view is helpful to identify cross-company hurdles (macro-level), which is of great importance regarding CE. It enables the companies to better respond to each other logistical needs and improve resource and waste recovery [2].

As depicted in Figure 2, the macro-level consists of all the members actively participating in the supply chain (SC), and each member embodies a different analyzable micro-level with their own set of customers and suppliers.

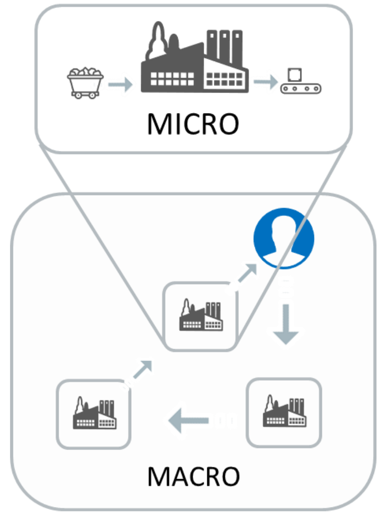


Figure 2: Micro- and macro- level

The Value Stream Analysis phase is sub-divided into three more specific steps, specified hereinafter.

3.1. Selecting product family & understand its product-life-cycle

First, a specific product family needs to be selected to reduce the complexity of the subsequent steps and to facilitate the collection of data, as well as the forthcoming analysis process of the current state. The chosen product family should be representative of the company. After a product family has been chosen, it is important to get an overview of the product's complete supply chain with all its respective processes (more important, if a macro-analysis is required). At this point, it is not important to have detailed knowledge about the individual processes but to get a general understanding.

If a macro-level analysis is requested, a supply-chain diagram with the correct sequence of companies and blank spaces for detailed data and information is needed.

3.2. Data collection

Subsequent data collection must be consistent with the basic levels of analysis previously mentioned. There exists a differentiation between micro-level and macro-level data. Usually, the micro-level data is companywide and easier to acquire and process, than macro-level data, which depends on the integration and level of communication between partners in the supply chain.

Thus, the micro-level emphasizes all the different internal processes along the value creation process. The indicative characteristics, needed to form the base for the current state value stream map, must be extracted from:

- interviews with process operators
- quantifiable and time-dependent measurements
- actual process data

On the other hand, the addition of a possible macro-level analysis, exposing all related suppliers and external factors to the supply chain, requires an extended set of data. To assess such supply chains, a supply chain management system or other types of intercompany communication could be helpful. The required information will be again derived from interviews with sales and logistics personnel, as well as departments leaders. Other influences like current or future policies affecting R-infrastructures and consumption might need to be considered.

At last, to clearly express the gathered data, metrics, also known as parameters or indicators, are introduced. They clearly represent actual quantifiable and comprehensible information. The applied set of parameters depends on the requirements, nature, and targets of the company. The task at hand for the internal coordinator or external consultant is to choose which indicators represent their goals best. A short product life cycle (PLC) and a high material consumption might help to identify, where resource maintaining processes might be possible, whereas high throughputs and reused resources rates help to identify where material recovery infrastructures could be useful.

The base set parameters are categorized around the vision of CE and directly relate to the resource flow and indirectly to sustainability. CE essentially tries to maintain, increase, and recover value through its cycles.

A selection of those indicators can be found in Table 6.

3.3. Current state C-VSM

Based on the two previous sections (selected product family and data collection), the current state of the VSM is to be created. This should first be done on a micro-level, and if needed further elaborated to a broader analysis on macro-level.

Micro-level

The micro-level VSM consists of the following three main categories, visualized in Figure 3:

A. Main resource flow, together with its respective auxiliary flow
B. Adjacent companies: customer & supplier
C. Information flow

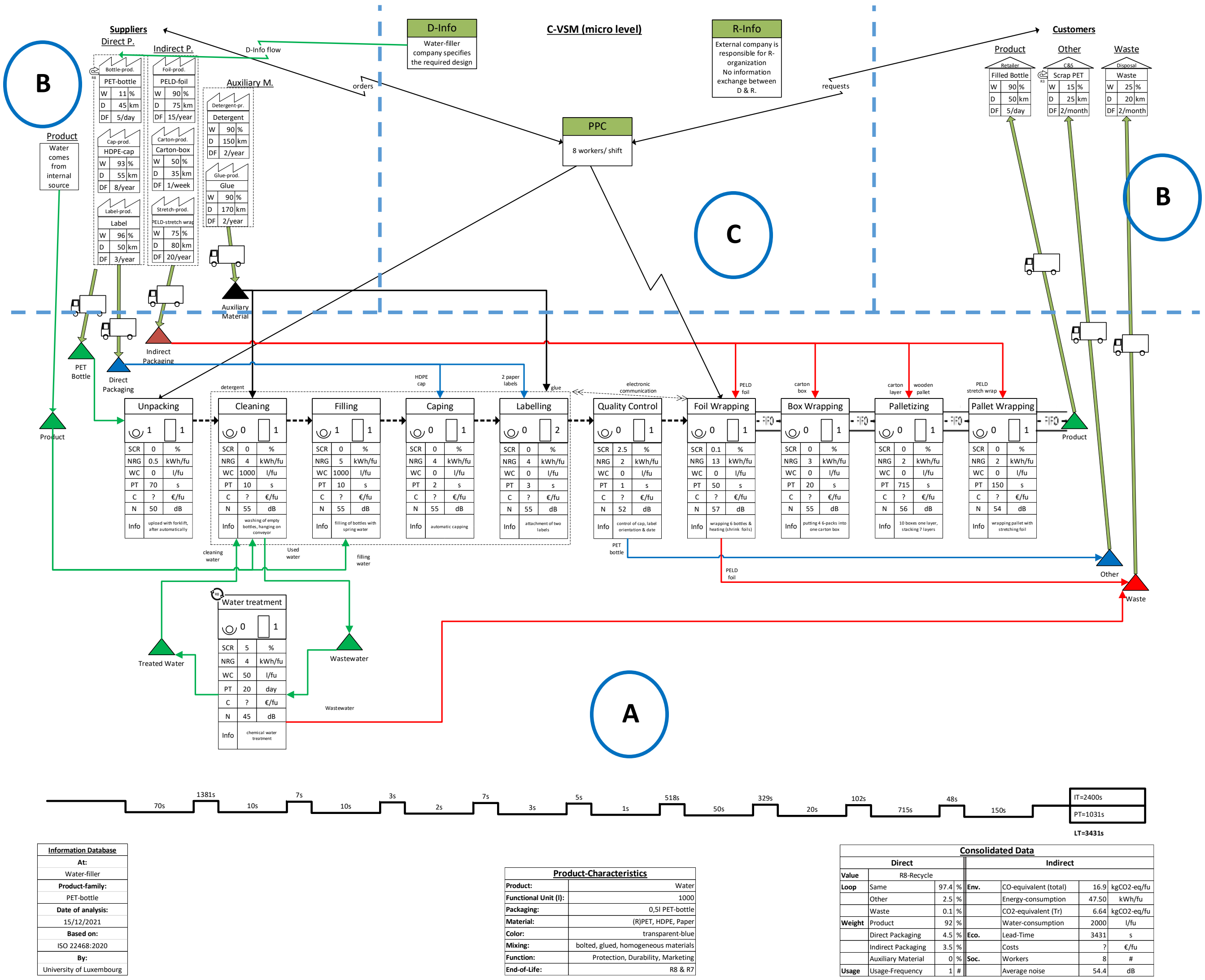


Figure 3: Typical setup of a C-VSM, current state, micro-level

Since the VSM method is oriented to the needs of the end customer, the customer should be placed first (upper right corner) with its associated parameters. Then, the outgoing external product flow is indicated. Further upstream, the current process steps with their corresponding data fields and finally the incoming external flow towards the suppliers are integrated into the VSM. The customers the same as the suppliers can be regrouped into different categories (actual product, packaging supplies, and auxiliary materials).

Now that all processes, suppliers, and customers are set, the resource flows around those elements need to be introduced and categorized. Product flows are resource flows directly related to the product and indicate the flow type in-between the main processes. The other resource flows serve as an extended, more holistic view regarding CE. To better distinguish between the different resource flows, they are color-coded. In the example depicted in Figure 3, the focus lies on the PET-bottles, why this one is color coded in green. Additional necessary packaging components like the cap and the label are labelled in blue, whereas additional packaging and waste flows are marked in red. Auxiliary materials like glue are marked in black.

The last components are the information flows and systems. An integral part of the VSM is the production planning and control unit, which allocates resources (processes), handles requests (customers), and issues orders (suppliers). At last, there are two information flows, indicating who is partaking in the design (D-info) and/or recovery (R-Info) process of the product.

The VSM is completed with an assessment line, which helps to visualize the most significant indicator. In traditional VSM, the same as in the example shown, this is the time (process-, idle- and lead-time). If the analysis has a different focus, it can also focus on water-, energy-consumption or waste amount.

Other components include tables like the product characteristics, information database, and consolidated data tables represented in Figure 3.

Macro-level

The micro-level VSM consists of the following three main categories, visualized in Figure 4:

A. Main supply chain partners, and their associated position on the value ladder
B. Information flow
C. Swim lanes representing the Value Ladder and R-Scala

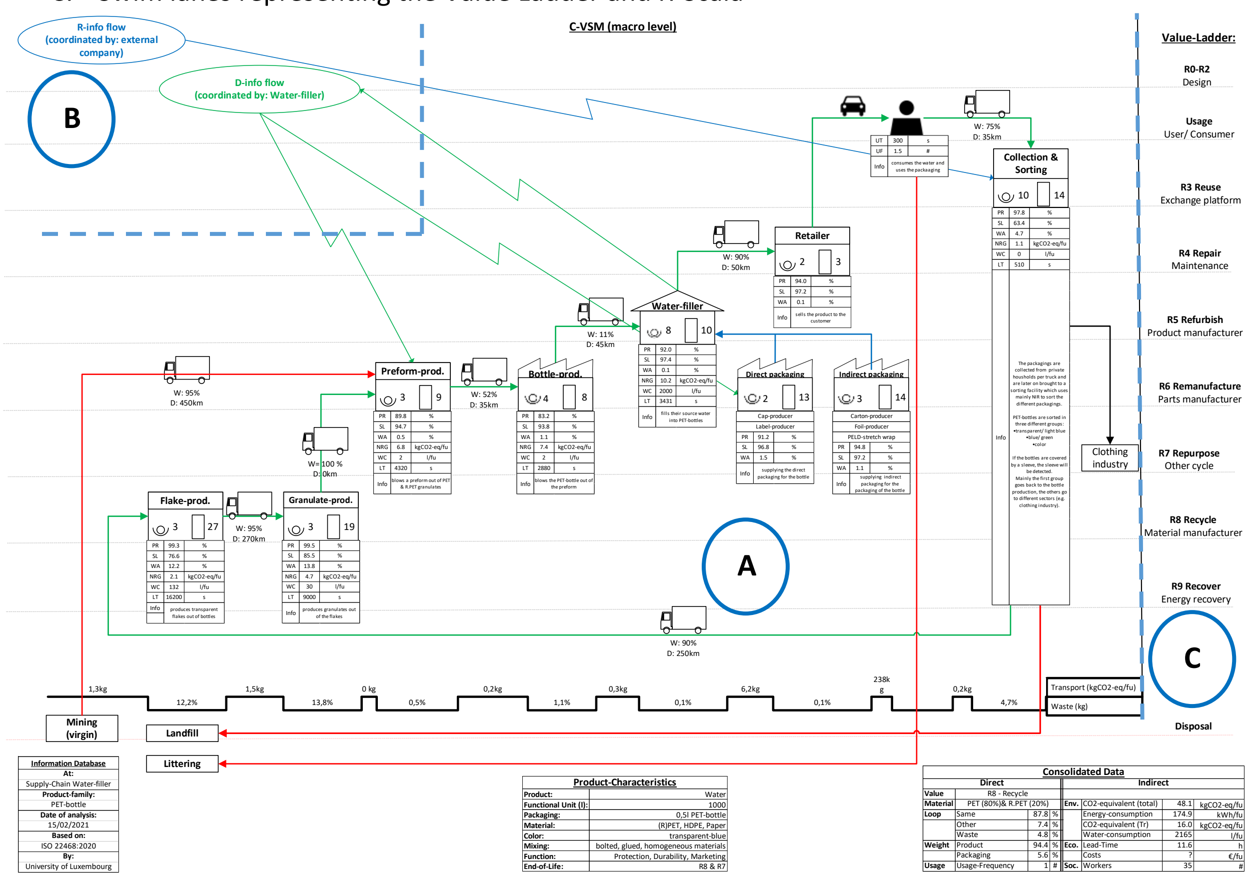


Figure 4: Typical setup of a C-VSM, current state, macro-level

Compared to the micro-level, the macro level focuses on the entire supply chain and the related resource flow. The macro-level, as shown in Figure 4, characteristically uses a swim-lane representation to illustrate the different CE-values and R9-equivalence of the different participants. On a micro level, the initial step was to start by placing the customer first. For the macro level, the end consumer/ user symbol represents the focal point and thus the first stepping-stone. From here, the other partners in the supply chain are gradually added. These are the upstream partners on the one hand (left side - suppliers) and the downstream partners (right side – user/ consumer & EOL-customer) who deal with the material recovery. In the CE approach, the downstream companies, i.e., those of the EOL, play an important role, and thus their processes and, above all, their process capabilities are to be examined in more detail.

The different R-levels are shown more in detail in Figure 5.

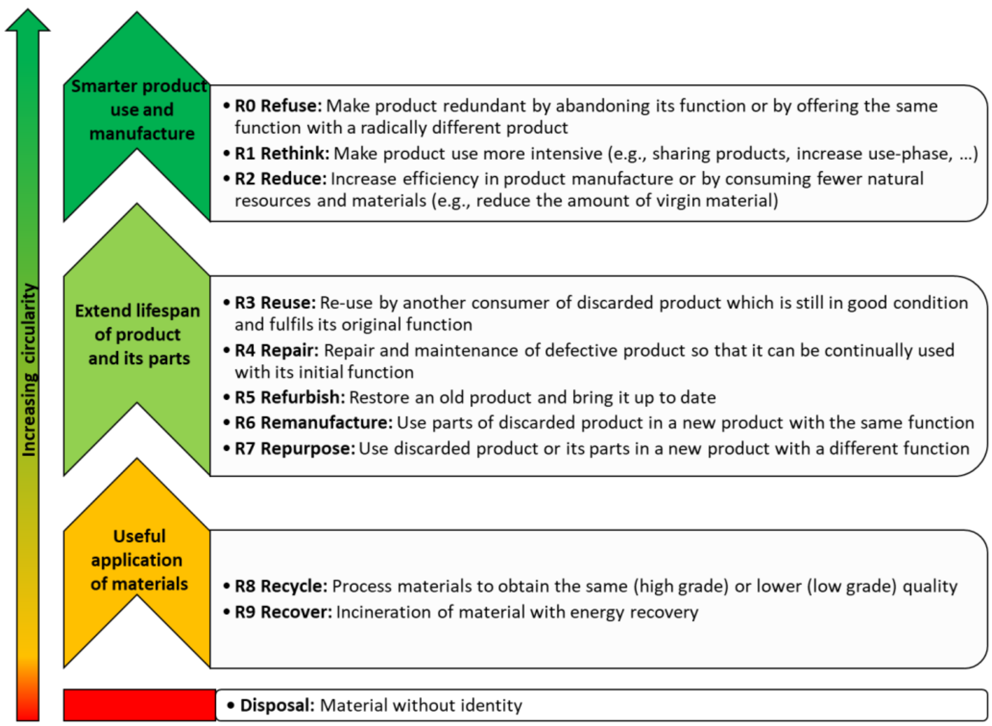


Figure 5. The 9R-framework [8]

The different resource flows use the same classification as the micro-level resource flows. There are again necessary, required, auxiliary, and reintroducing resource flows. Additionally, it is possible to use simple labels to represent the virgin material source, the final waste destination, and other elements like the "Littering" or "Clothing industry" in that supply chain.

This concludes the composition of the macro-level value stream map. But as previously mentioned to complete and help assess the map a timeline based on any indicator or metric can be chosen and displayed on the bottom of the map. As well as tables, which summarize and characterize the nature of that map, are added.

4. Value Stream Design

The Value Stream Design phase is sub-divided into two more specific steps, specified hereinafter.

4.1. Identify process-improvement

The first part is similar to the traditional VSM process and aims to find the local improvement potentials within the processes. Once all the essential data has been collected at the micro level and a current state of the process chain is available, it is possible to identify improvement potential through continuous improvement flashes.

The identification of improvement potentials is based on the following four points [8]:

1) Close loops: With one of the main aims of CE being to close resource loops, the first step is to find out and highlight processes which have a high outflow rate and identify the reasons behind this.
2) Slow loops: Another major aim of CE is to slow loops, what refers to extending the lifetime of products and not slowing the production or recovering processes. This is however mainly modifiable through the product design. Nevertheless, the macro-level viewpoint can help to detect possibilities to extend a product's lifetime.
3) Minimize waste: The C-VSM helps to quantify the amount of waste at the different processes and thus detect the main waste bottlenecks. Wherever there is an outflow which is not used (e.g., disposal), it is worth looking for possibilities of further use.
4) Sustainability: Since sustainability plays a major role within CE, the three pillars of sustainability should not be neglected.
    a. *Environmental:* Since the C-VSM contains certain environmental parameters (e.g., water- or energy-consumption), the aim is to improve the processes with the highest environmental influence.
    b. *Economic:* Like the traditional VSM, the aim here is to improve the throughput time in consideration of the 7 types of waste (transport, inventory, motion, waiting, over-processing, over-production, and defects).
    c. *Social:* This is a more critical and difficult to judge step since the social aspects are mostly highlighted as a weak point of sustainability VSM, where there is still room for improvement.

The listed categories of potential improvements are sorted by CE priorities and should be used as a guide to identify potential weaknesses. The C-VSM with the highlighted improvement potentials is the second map and can be performed at both the micro and macro level.

4.2. Design a future state

After having identified (with an ideal state in mind) and visualized all possible improvement potentials in the previous step, it is now time to check what is actually possible. Based on the identified deficits in the system, it should be reviewed, which improvement potential makes sense. As the list of improvement potentials is ordered based around those four CE principles the following guidelines follow the same order and briefly explain how to possibly achieve those principles. Some ideas need the collaboration of external partners, and as such can be visualized and developed on a macro-level analysis.

1) Close loops – closing the loop between post-use and production
   - Encouraging recovery by the introduced R-infrastructures through product design, and collaborations between partners and consumers (improving D- and R-Information flows)
   - Closing the process loop by implementing new processes, which use outgoing resource flows and reintroduce value back into the production chain by either creating the same or lower quality products (other production lines possible)
2) Slow loops – slowing the loop by designing long-life goods and extending product life
   - Encouraging reuse, and thus increasing the product life cycle, through an adaptive and modular product design
   - Maintaining products at their highest value through different R-infrastructures, like refurbish and repair services (external partners)
3) Waste – reducing the amount of waste material
   - Increasing process efficiencies by adapting new processes or changing process inputs
   - Increasing number of quality control points to limit the propagation of defects through the production line → the earlier a defect is detected, the better
   - Reuse of waste by closing a loop or recovering the value through an internal or external process
4) Sustainability – management and design of resourcing, planning, procurement, reprocessing, and production to maximize economic functioning and human prosperity (sensu latu) [16]

   Environmental
   - Minimizing water consumption by introducing wastewater treatment facilities and/or adapting processes to use less water
   - Implementing sustainable energy resources and increasing energy efficiency (e.g., energy recovery systems)
   - Minimizing delivery frequency and transport by improving packaging and weight
   - Use of different resources and materials to limit pollution and toxicity

   Economical
   - Implementing continuous product flow and a supermarket pull system
   - Minimizing lead time through the elimination of bottlenecks, over-processing, and over production – implementation of a pacemaker process

   Social
   - Improving work safety and processes to minimize the number of incidents and maintain worker health (noise level, toxicity, workload, risks)
   - Introducing training and workshops to increase qualification

5. Value Stream Planning

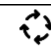
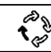
The Value Stream Planning phase is sub-divided into three more specific steps, specified hereinafter.

5.1. Catalogue of improvement measures

All proposed changes must be considered in the following documentation. A detailed definition of the procedures associated with tasks and actions is summarized in a list of measures. To avoid misunderstandings, the SMART method should be used to describe all actions. The SMART method implies the development of "specific, measurable, accepted, realistic, and time-based" definitions. All measures can be summarized in a table (see Table 4).

Table 4, shown in the Annex, holds the information about:

Table 1: Priority

Highest rank	
Lowest rank	

- ➢ The measures and steps needed to follow
- ➢ The timeline of the different steps of the improvement process
- ➢ The responsible employees or department in charge of the implementation and review
- ➢ The progress indication, indicated by the progress indicator
- ➢ The measures associated goals
- ➢ The goals associated priority based on the applied CE-principal, indicated by the priority arrow (Table 1)

5.2. Discussions, Workshops

The next step is to communicate and discuss the received results internally with the responsible employees as well as the company's management. All the beforehand determined company visions and targets need to be reiterated and conceptualized. Based on those visions the discussions should constructively focus on the possible measures at hand and conclude why or why not some measures are or aren't implementable.

A practical approach is to organize a workshop with all the interested and responsible people. Where firstly, the current state C-VSM is presented and checked for correctness. Secondly, all attendees receive a pad with a certain color of sticky notes and stick possible suggestions for improvement on the current state. These suggestions are afterward compared with the previously worked out suggestions. Then for the third step, the most important suggestions, which can actually be implemented, should be agreed upon. The goal of this approach is to collectively adapt and, if necessary, expand the previously worked out improvement suggestions.

To assess the willingness of the external partners to contribute to circularity, discussions between different supply chain members, as well as consumer workshops and/or a market analysis should be organized. A huge part of the close and slow principal depends on the consumer, such that the overall moral of the consumer needs to shift towards reuse, refurbish or at least recycle. To then enter the recovery phase of the cycle deeper collaborations between members should be implemented. Therefore, in the same fashion as for the internally implementable measures discussions should be held and the different solutions/improvement potentials should be pitched to each other. The goal is to create collaborations between the different supply chain partners and to develop a collective target.

In fact, external factors like policymakers are nowadays deeply invested in CE, such that some governments try to enable circularity by engaging as consultants and enabling tools to enhance circular development on a national or regional scale [13]. Their tools conclude the creation of regulatory frameworks and financial instruments, and most importantly an exchange platform of knowledge. Their informative exchange platforms could help the internally developed improvement process and collaborative platforms between external partners.

After finalizing the now adapted and globally agreed upon catalogue of measures, the latest version, which clearly indicates the implementable changes, should be distributed to the respective coordinators.

5.3. Implementation

Based on the agreement, the defined measures are implemented in the respective organizations as part of a continuous improvement process. This step is about implementing what was previously planned. The implementation process takes place in a simple iterative procedure based on the final catalog of measures mentioned earlier. The respective staff should review the current state of the process, evaluate the implementation steps, and determine the best way to begin the change toward the target state. The implementation process begins with the first step, which can be either adjusting the process or realigning or changing the flow of resources. After a series of initial changes, the responsible staff member must review the new current state, prepare a report to the coordinator, and inform him or her of the status or any setbacks. With this assessment, implementation, and reporting on a set, the implementation process is complete.

Moreover, it would be beneficial to form a council, which overviews all the implemented changes across the supply chain and tries to keep all the different members up to date. Such a council should consist of multiple improvement coordinators and directly report to the management level of each member, but this seems to be a quite extensive task and could lead to new problems/bottlenecks.

6. Assessments

The last possible step is to make certain assessments based on the information gathered. For these assessments, important performance indicators must be determined. This may be of interest for later monitoring of the implemented changes and determining the actual performance of the system. The proposed indicators could help to form these performance measures. In addition, it is possible to compile relative comparison indicators that represent the actual gain or loss of the future state compared to the current state [4].

Essentially, a Key Performance Indicator (KPI) describes a process and its key values, such as energy consumption, scrap rate, or value-added percentage. Relative comparison indicators show the actual gain or loss after implementation of the future state. The difference between the performance indicators of the current and the future state indicates the absolute profit or loss. By comparing the absolute gain or loss with the current state, a relative comparison indicator such as the energy savings indicator can be formed, which, if positive, shows that the future state consumes more energy than the current state.

In the case of the example depicted in Figure 3, the lead time, the scrap rate, the energy- and water-consumption, as well as the process time, cost, and noise were chosen. That set enables the creation of relative comparison and key performance indicators:

1) Key performance indicators within one process:
   - Scrap rate - highlights the amount of scrapped resources relative to the input resources
   - Value-adding share – the ratio between the process time and lead time
   - Non-value adding share – the ratio between the idle time and lead time
2) Relative comparison indicators (usually in %) between 2 processes or entire facilities relative to the current state:
   - Energy savings – energy consumption difference between the target and current state divided by the energy consumption of the current state
   - Water savings – water consumption difference between the target and current state divided by the water consumption of the current state
   - Cost savings – cost difference between the target and actual state divided by the costs of the actual state
   - Average noise level – average noise difference between the target and actual state divided by the average noise level of the state

It is noticeable that some key metrics are process-related and thus only can directly be compared to other processes or need to be averaged over the entire facility/system and then be compared to another facility/system, e.g., the scrap rate or the noise level. Some metrics can also form total values, like the process time, idle time, lead time, energy, and water consumption. To ensure a continuous improvement process all the assessment criteria need to be constantly monitored and checked.

This was the last step of the C-VSM procedure. The next part is the annex, which includes a table with the symbols, a table with possible indicators, as well as a suggested setup for a catalogue of improvement measures and last an example outlining the different stages.

7. Annex

7.1. Symbols

Table 2: C-VSM symbols (1) [2], [4]

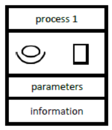
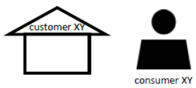
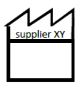
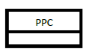
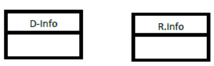
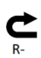
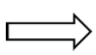
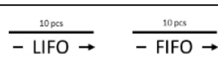
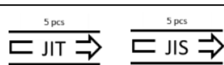
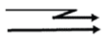
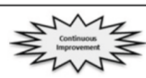
Symbols			
Category	**Symbol**	**Term**	**Additional information**
processes		process	process data box:  number of operators number of resources (machines, tools, processes, ...)  MICRO: material-, energy- or data-driven process MACRO: indirect supplier
processes		customer process/ consumer	MICRO: differentiation: end customer (symbol customer process) customer/plant (symbol external sources)  MACRO: original equipment manufacturer (symbol customer process) consumer/user
processes		supplier process /external sources	MICRO if supplier also customer: symbol for customer process  MACRO direct supplier
processes		business process	production planing and control, allocates human resources, raw materials and equipment
processes		business process	R-Info: active in the resource retake D-Info: active in the design process
processes		circular arrow	all internal processes classified based on the R9-scala
processes		reintroduce arrow	all external R-infrastructures which reintroduce resources back into the loop, either as customers or suppliers
processes		bottleneck	position in value stream diagram: above process symbol
product flow		resource flow	resource flow - material flow additional infromation: reintroduced, direct, indirect or auxiliary
product flow		PUSH product flow	inbetween process product flow controlled by upstream processes
product flow		external product flow	external logistics, from suppliers or to customer
product flow		LIFO lane or FIFO lane	element of process flow control, additional information: process quantity
product flow		Just-in-Time delivery or Just-in-Sequence delivery	element of process flow control, additional information: process quantity

Table 3: C-VSM symbols (2) [2], [4]

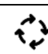
product flow		stock	inventory triangle, additional information: reintroduced, direct, indirect, auxiliary
product flow		supermarket	element of PULL system (product flow controlled by downstream processes) additional information: number of products or range
product flow		withdrawal	element of PULL system (product flow controlled by downstream processes)
product flow		transport	transport (mode can vary) additional information: delivery frequency
planning / control		information flow (electronical or manual)	information flow from the PPC, the R-Info or D-info
planning / control		GoSee production planning	manual observation of process flow
general		Continuous Improvement flash	incl. description, numbering and possibly coloured highlighting (e.g. yellow/orange)

7.2.Possible table for the improvement measures

Table 4: Possible table for the improvement measures

Nr.	Improvement potential	Measures and goals	Responsible employee/department	Status	Priority
1					
2					
3					
4					
5					

Table 5: Possible rank system for the different goals

Close Loop	
Slow Loop	
Waste	
Sustainability	

7.3. Possible indicators

Table 6: Possible indicators (1) [2], [4], [14], [15]

List of abbreviations				
Type	**Abbreviation**	**Indicator**	**Unit**	**Definition**
Close	**SL**	**same loop rate**	%	raterate of how much reintroduced resources to total amount of resources
	CC	**cycle count**	#	sum of components, which underwent the cycle "i" times the number of cycles type "i", divided by the total quantity of components
slow	**L**	**longevity**	#	sum of components, with the age type "i" times the age "i", divided by the total quantity of components
Waste	**W**	**waste**	quantity	amount of waste leaving the process or facility
Environmental	**CO2-eq**	**CO2-equivalent**	quantity	equivalent of CO2-emissions per process
	DF	**delivery-frequence**	quantity	amount of deliveries per period
	NRG	**energy-consumption**	quantity	energy usage per process
	NRGT	**energy-transport**	quantity	energy usage per transport
	PW	**product-weight**	quantity	net product weight
	RMR	**raw-material-rate**	%	amount of virgin material used per product
	TW	**total-weight**	quantity	total weight of product including packaging
	WC	**water-consumption**	quantity	water usage per process
	WQ	**water-quality**	quality	affected water qualtity due to process, total dissolved solids, chemical emissions
Enconomical	**CT**	**cycle-time**	time-unit	time intervall for the completion of one product within a process
	DT	**downtime**	time-unit	total time period needed to detect and correct errors or failures
	IT	**idle-time**	time-unit	time period between two processes (i.e. storage and transport)
	LT	**lead-time**	time-unit	time period from the date of order receipt to the transfer of the product to the end customer
	PC	**process-costs**	€	running costs per process
	PT	**process-time**	time-unit	dwell time of the product within a process, machine or station
	RR	**rework-rate**	%	number of intermediates or products tat can be corrected subsequently
	SR	**scrap-rate**	%	number of defective inermediates or finished products in relation to the total amount
	T	**throughput**	quantity	number of parts undergoing a process per period of time
	TaT	**takt-time**	time-unit	available working time divided by the customer demand
	TC	**transport-costs**	€	costs associated to transport mode
	TT	**transport-time**	time-unit	time period for teh transport or movement of raw materials, intermediates or finished products
Social	**N**	**noise-level**	dB	noise-level at the location
	EL	**education-level**	#	education level of operator, knowledge about waste management, processes
	PD	**physical-demand**	#	amount of difficulty to perform physical activities
	WER	**work-environment-risk**	#	risk based on work-environment (E-electrical systems, H-hazardous material, P-pressurized systems, S-high speed components)

7.4. Step-by-step guide

	N°	Steps	Notes	Status
Pre-requisite	0	Goals and Vision	➢ Understand the companies' vision and operations	○
			➢ Set possible targets and goals, e.g., reduce waste or increase throughput (create, maintain, or recover value)	○
VS-Analysis	1	Product Family	➢ Analyze available products	○
			➢ Group the products into product families with similar properties, process steps and processing volumes	○
			➢ Select from the multiple product families the most relevant and representative	○
	2	Data Collection	➢ Interview process operators	○
			➢ Gather process data (available metrics, see Table 6)	○
			➢ Interview logistic and sales personnel	○
			➢ Review supply-chain and product life cycle, establish information exchange with external partners	◌
	3	Current State C-VSM	➢ Start with the visualization by placing all customers on the right upper corner	○
			➢ Continuing upstream in reverse order place all process steps in the center	○
			➢ Finish the main product flow with the placement of the suppliers on the left upper corner	○
			➢ Add the different resource flows entering or leaving the different processes	○
			➢ Add the production planning and control unit, and the D- and R-Info flows	○
			➢ Place the customer on its respective lane	◌
			➢ Add all the other external partners on their lanes	◌
			➢ Add if necessary other labels for other resource destinations or sources	◌

VS-Design	4	Identification of process improvements	➢ Analyze the current state map and identify all the possible deficits or improvement potentials (close and slow loops, waste management, pursue sustainable solutions)	○
			➢ Establish an order of priority	○
			➢ Highlight all potentials on the map with a continuous improvement flash	○
	5	Future State C-VSM	➢ Review all potentials and develop implementable solutions/measures (see 4.2)	○
			➢ Adapt the current state map and add all the solutions	○
VS-Plan	6	Measurement’s catalogue	➢ Collect all the solutions and form a coherent document (see Table 4) clearly describing the required steps	○
	7	Workshops	➢ Organize internal workshops to review all procedures and solutions	○
			➢ Introduce deeper collaborations with external partners and supply chain members	○
			➢ Analyze costumer markets and recovery processes	◌
	8	Implementation	➢ Execute and follow the catalogue of measurements	○
			➢ Update the status and continuously monitor the implementation process	○
			➢ Keep all involved members up to date and increase macro level transparency	◌
End	9	Assessment	➢ Form a set of KPI	○
			➢ Monitor the KPI and relative comparison indicators	○
			➢ Establish decision factors for the different indicators	○

○ micro level

◌ macro level

8. Case study example – PET-bottle

8.1. General Information

The following example, shown in Figure 6, is a manufacturer of PET preforms and bottles. The company uses internally produced preforms and inflates them for some customers in the next process step. The pellets for the preforms are a combination of mostly virgin pellets or recycled pellets from defective preforms. The blown bottles are labeled, inspected, and then packaged for shipment.

The customer is supplied 5 times a day due to the low storage capacity. The distance is 50 km, and the weight of the bottle is only 15% of the capacity of the delivery trucks. The waste is delivered by a truck with a capacity of 60% once a week to a waste company (customer) 40 km away. The 2 preform injection molding machines operate automatically with a reject rate of 2%. They consume 2.5 kWh of energy and 50 l of water per functional unit. The average 2% scrap material is thrown into metal boxes together with other scrap material, while the good parts are temporarily stored in cardboard boxes lined with a film. The machines generate a noise level of about 75 dB. The next process, bottle blowing, also uses 2 machines with 2 molds and one operator. Due to the lack of a quality control station, the reject rate for this process is 0. Both machines consume 6 kWh of energy and 100 l of water per functional unit. These machines are slightly noisier and operate at a noise level of 80 dB. The labeling machines are automated and still have no reject rate. Their energy consumption is comparatively low at around 0.75 kWh per functional unit and a noise level of 65 dB. An automatic machine with one operator is used for the actual quality control. The reject rate of 5% is made up of 3% faulty bottles and 2% incorrectly applied labels. These 2% cannot be reapplied to the labels. They consume 0.75kWh of energy per functional unit and operate at a noise level of 65dB. The packaging is done by a machine and an operator. While 0 bottles are discarded, packaging material such as cardboard or film may be defective and is discarded. 7 layers of 240 bottles each form the final fully stacked pallet. The last operation consumes 1kWh and generates a noise level of 55 dB. The in-house granulation process takes the scrap material and processes it into granulates. This process consists of one machine and one operator, which visually checks the input scrap and throws ultimately 25% away. The machine consumes around 1.5kWh of energy and operates at 75 dB.

The granules are delivered daily by a tanker truck with a capacity of 100% from a granule supplier 250 km away and stored in silos. Labels are delivered once a week with a weight capacity of 95% from a local producer 2 km away. Cardboard and films are delivered weekly with a weight capacity of 70% from another local supplier 35 km away.

Production planning and control (PPC) allocates resources to the preform injection molding, bottle blowing and packaging processes electronically and to the labeling and quality control steps manually. The water bottler specifies the desired bottle design without any input from the recycling company.

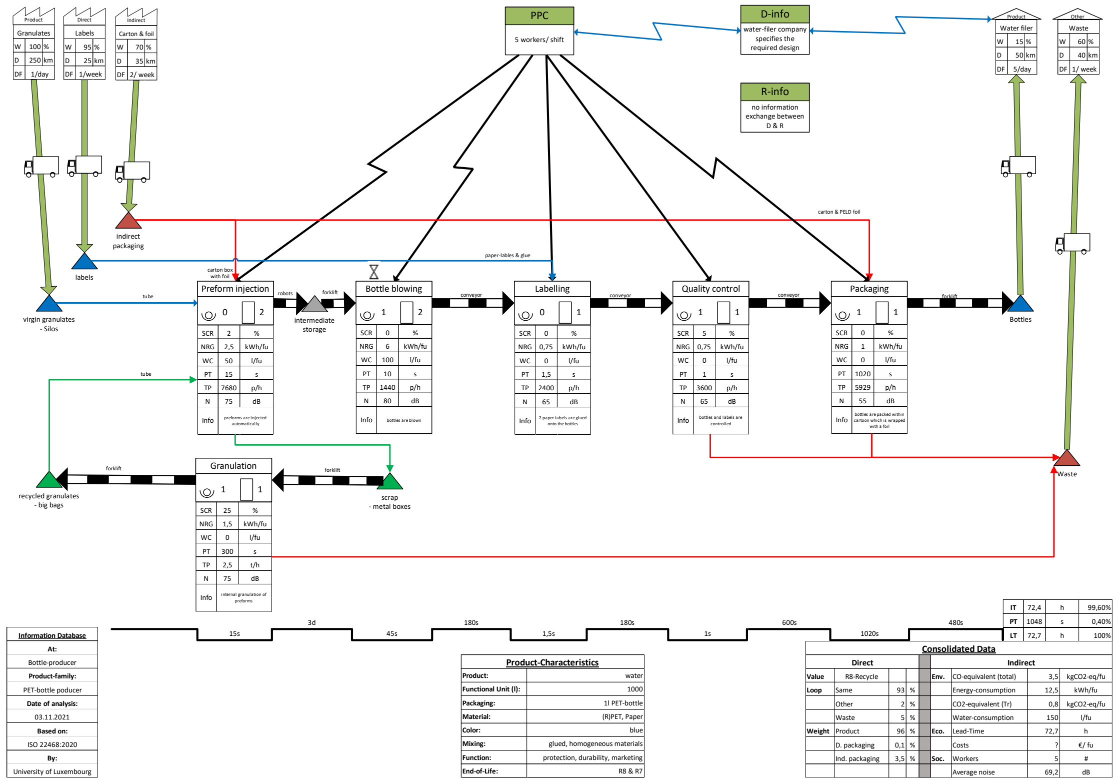


Figure 6: Case study, current state C-VSM

8.2. Solution

Following the four CE goals mentioned in the value stream design section, certain exemplary improvement potentials are listed in Table 7 and visualized in Figure 7.

Table 7: Case study, improvement measures catalogue

Nr.	Improvement potential	Measures and goals	Responsible employee/department	Status	Priority
1	No communcation between D-info and R-info	Implementation of information exchange between retake and design partners, to gurantee value recovery by the collecting and sorting facility at the end of life stage	Design manager		
2	High scrap rate at quality control	Addition of a quality control unit to sort out the defect bottles after the blowing process, because 3% of the scrap are caused by the blowing process > scrap rate from 5% to 2%	Recycling manager		
3	High scrap rate at granulation	Addition of a sorting unit, which categorises the the mixed scrap material based on their specifications to achieve better granulations and additives > scrap rate from 25% to 3%	Recycling manager		
4	Long idle time at the intermediate storage	Adoption of a pull system	Logistics manager		
5	Empty transportation to customer, bottleneck and high energy consumption	Installation of a blowing unit at the customers facility and changing the business model from providing a product to provided a service > weight capacity from 15% to 100% (local)	Upper management, logisitcs department and production manager		

Marking the suggested improvements within the VSM allows for better visualization and recognition. These are by no means all possible improvements, but only a few examples.

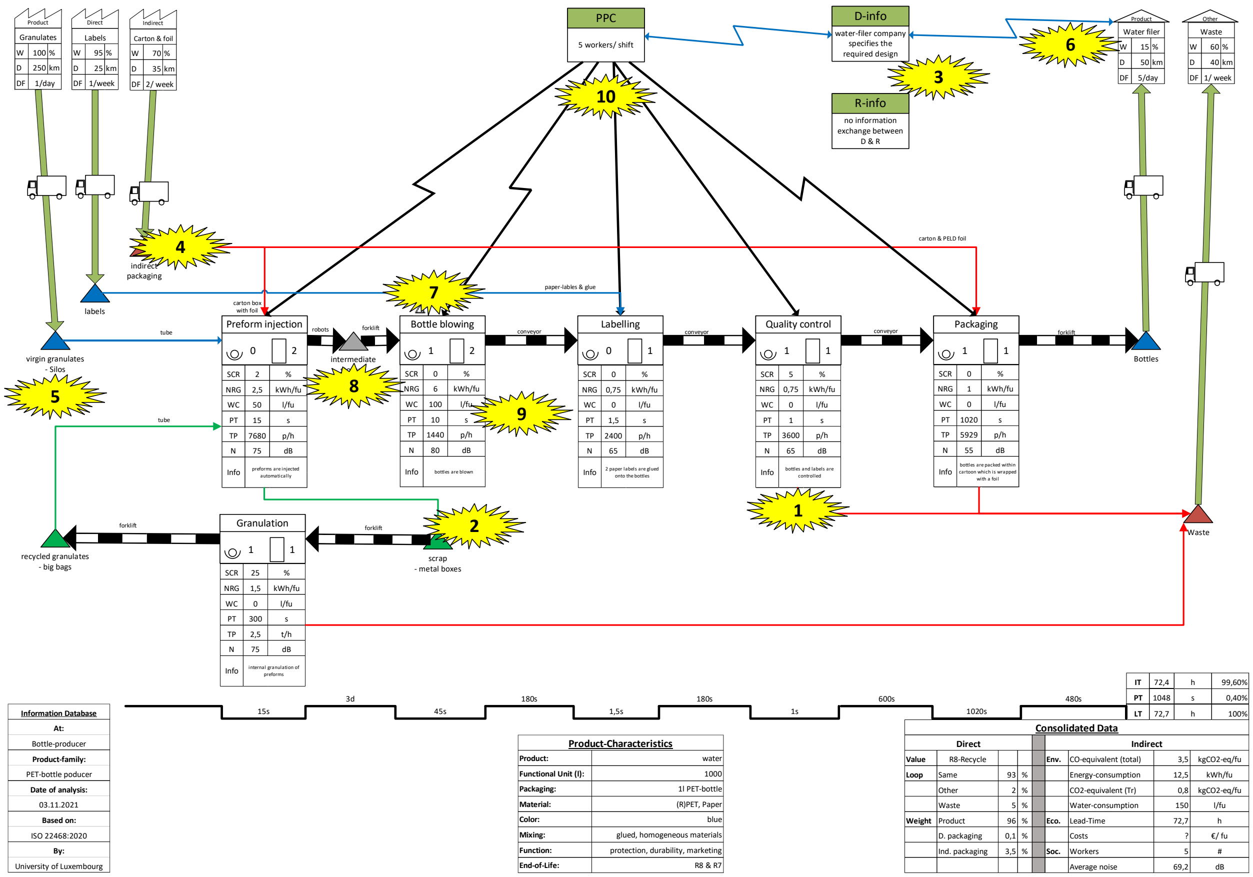


Figure 7: Case study, current state C-VSM, identified improvement potentials

The future state (Figure 8) will have a pull system where the molds are stored in an internal supermarket after preforming the various bottles. The bottle blowing process will take the required number of preforms from the supermarket.

To optimize the granulation of the discarded preforms, a sorting process is introduced to distinguish between the different types of rejects.

The first quality control checks the bottles before the labeling process, which opens the possibility of scrapping the bottles directly after the blow molding process and thus minimizing the reject rate in the second quality control after the labeling process.

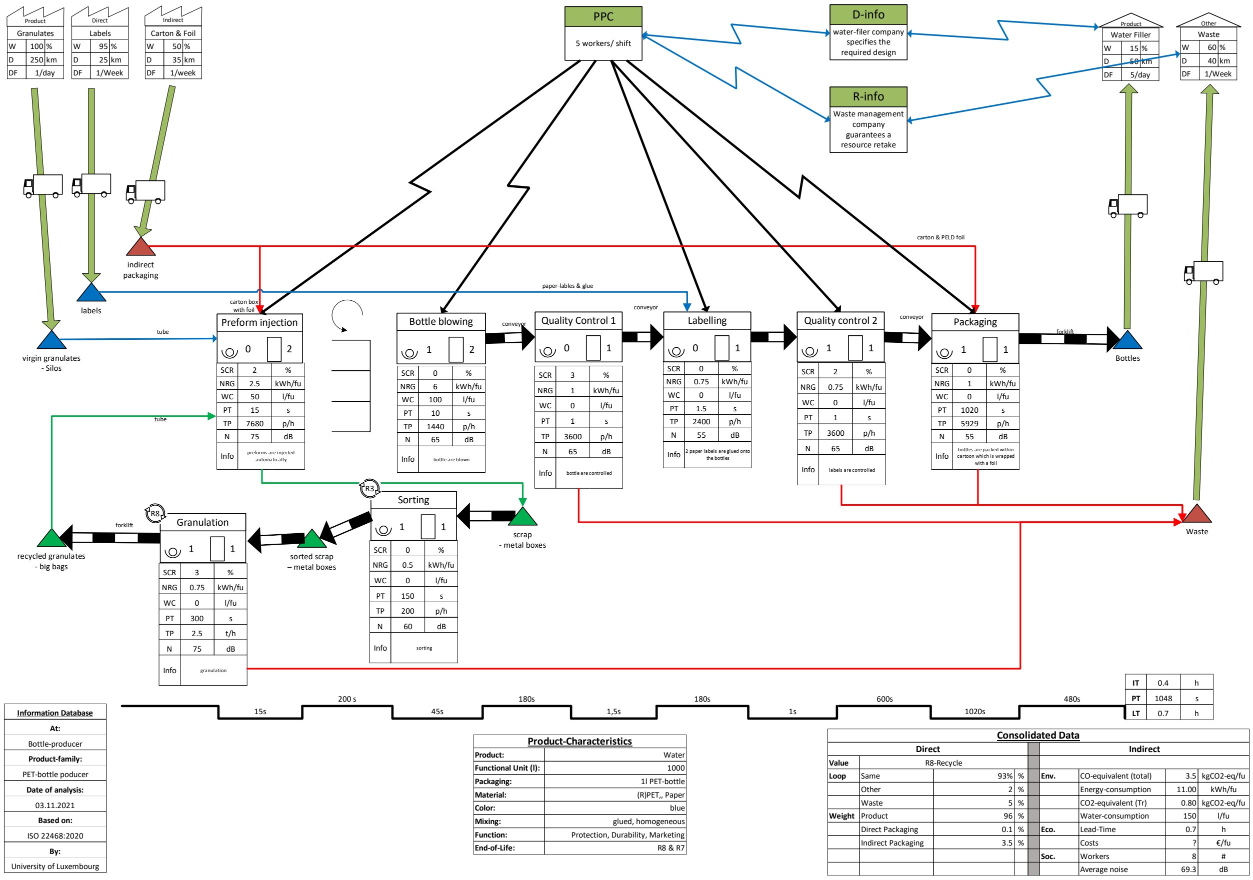


Figure 8: Case Study, future state C-VSM

The assessment of this future state yields Table 8:

Table 8:Case Study, Assessment

Process/Facility	Key Performance Indicator	Relative Comparison Indicator
Granulation	SCR went from 25% to 3%	decrease of 88%
Quality Control 2	SCR went from 5% to 2%	decrease of 60%
Total Idle Time	IT went from 72.4h to 0.4h	decrease of 99.4%

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Contact details:

Jeff Mangers
Manufacturing Engineering
Doctoral student

UNIVERSITÉ DU LUXEMBOURG

Kirchberg Campus
6, rue Coudenhove-Kalergi
L-1359 Luxembourg
T +352 46 66 44 5710

jeff.mangers@uni.lu / www.uni.lu

Univ.-Prof. Dr.-Ing. Peter Plapper
Manufacturing Engineering
Course Director

UNIVERSITÉ DU LUXEMBOURG

Kirchberg Campus
6, rue Coudenhove-Kalergi
L-1359 Luxembourg
T +352 46 66 44 5804

peter.plapper@uni.lu / www.uni.lu