Datum
2018-02-26

Dnr
2017-001955

Projektnr
44222-1

Energimyndighetens titel på projektet – svenska	
Digitalt Verktyg för ökat resursutnyttjande in WEEE (WEEE Digit)	
Energimyndighetens titel på projektet – engelska	
Digitalization tool for increased resource usage in WEEE (WEEE Digit)	
Universitet/högskola/företag Chalmers Tekniska Högskola AB	Avdelning/institution Produktionssystem/IMS
Adress Hörsalsvägen 7 A, 41296 Göteborg	
Namn på projektledare Björn Johansson	
Namn på ev övriga projektdeltagare Ilaria Barletta, Ilker Erdem, Sverker Sjölin, Henrik Jilvero	
Nyckelord: 5-7 st WEEE, återvinnig, digitala verktyg, modellering, simulering, robotik, fixturering	

Förord

WEEE-Digit är finansierat av RE:Source och Stena Technoworld AB, inblandade parter och forskare är mycket tacksamma för supporten till ett lyckt projekt.

Innehållsförteckning

Box 310 • 631 04 Eskilstuna • Besöksadress Kungsgatan 43
Telefon 016-544 20 00 • Telefax 016-544 20 99
registrator@energimyndigheten.se
www.energimyndigheten.se
Org.nr 202100-5000

Sammanfattning

WEEE-Digit har visat på att digitala verktyg kan förbättra hållbarhetsaspekterna avsevärt vid återvinnig av elektronikskrot. Digitala modeller av hårddisksåtervinnig har utvärderats och ett koncept som snabbt och effektivt kan demontera både magneten och kretskortet från en rad olika varianter av hårddiskar har designats som ett proof of concept. Nästa steg blir att växla upp denna insats med fler aktörer för att påvisa generaliserbarheten forskningsmässigt samt att generera nyttan i det vi hittat till fler återvinnigsindustrier i Sverige.

Summary

WEEE-Digit has shown that digital tools can improve sustainability aspects considerably when recycling electronic waste. Digital models of hard drive recycling have been evaluated and a concept that quickly and efficiently dismantles both the magnet and the circuit board from a variety of hard disk drives has been designed as a proof of concept. The next step will be to expand this effort with more partners to demonstrate the generalizability of the conducted research and to disseminate the benefit of what we found to more recycling industries in Sweden.

Inledning/Bakgrund

With digitalization that supports decision-making, automated handling and dismantling used in different situations enables resource usage to be maximized. In an ongoing project "Critical raw materials in the Nordic Countries-Recovery potential and opportunities for removal of bottlenecks" funded by the Nordic council of Ministers, the results show that inadequate performance in separation and sorting (technology bottleneck) hampers critical raw materials (CRM) recycling as well as reuse of products containing CRMs. Therefore, by increasing the use of available resources, the efficiency thresholds that convert performance-wise inadequate technologies into feasible value-adding systems can be realized.
Selective treatment using robotics and digitalization puts also attention to human robot integration. Which variations can robots handle and which remains manual?
In a project called REMENANCE [1] a pilot-scale production cell was developed where the hard disk drives were fed into the cell, and then cut the corner where the neodymium magnet (NdFeB) is placed. The project investigated many products with NdFeB magnet content and the conclusion was that the hard disks with homogeneous geometry were the most suitable for which to develop a robotic process. Another key-issue is that a hard disc drive has other valuable material content. As a result, the pre-treatment stage of the used hard disc drive was handled separately and the circuit board was manually removed.
The WEEE (Waste of Electrical and Electronic Equipment) Directive stipulates which control has to be made on WEEE before transported across borders for reuse. For hard drives, there are also specific requirements with regard to erasing information on them. If hard drives can be sorted for either reuse and recycling

purposes, and digitalization is used to develop quality control and reduce cost, then more products can go back into use phases through circulation. This means that route handling/lifting will increase in comparison to today's existing reuse. Impact on ergonomics are negative today since dismantling steps are performed manually. Furthermore, a recycling process requires to be considered similar to a robust manufacturing system. The set-up and design of a conceptual cell that can dismantle the HDDs does not exist in recycling today. The innovation in this pre-project lies in the use of robust manufacturing system requirements on a recycling process.

Genomförande

The main objective of the WEEE Digit project was to establish a digitalized reuse and recycling process employing robotics and an adaptive fixture solution for enhanced material recovery from HDDs. To reach the overall goal, the following sub-objectives have been addressed:

- Determine the flexibility of the separation of HDD process, i.e.: what variability in HDD design would a commercial process be required to handle?
- Determine the required quality of the sensors and robot, with respect to accuracy. Is the present technology capable enough for a feasible process?
- Suggest a feasible process model which describes the work distribution between human-robot of the present recycling process, with respect to pre-processing and manual handling.

The concrete deliverables were formulated and treated as work packages in order to organize the workflow conducted by respective parties. These deliverables were described in the following table.

Deliv.	Description
D1	List of process variables which can be automated using simulation of a robot and automated flexible fixtures, such as max/min size, weight, ESD protection requirements.
D2	Determine the technological capabilities of individual resources/fixtures/tools.
D3	Suggested digitalized solution that will remove the circuit board in hard disks using the robot and automated flexible fixtures
D4	A proof of concept simulated robotic cell for recycling of different hard disks
D5	A method for feasibility analysis/decision support regarding automation in order to replace manual operations
D6	Dissemination of knowledge through workshops and a scientific publication

Research methods and methodologies adopted for evaluating the sustainability implications of the new robotic cells:

For the proposed technology to land e-recycling facilities, it is important to understand what kind of impacts on sustainability it will cause, not only on a factory level but also on a company and societal level. In order to do so, the following activities have been carried out:

- semi-structured interviews
- concept-map exercises
- the development of a high-level methodology to analyze sustainability impacts of the new robotic cell.

Three experts on WEEE recycling and have been interviewed:

- Sverker Sjölin, technical specialist at Stena Technoworld AB (project member of WEEE Digit)
- Henrik Jilvero, R&D and project manager at Stena Recycling International AB (project member of WEEE Digit)
- Federico Magalini, consultant with decades of experience in automation and policy making for WEEE.

As Stena Metall is the first recipient of the flexible-feature technology for HDD disassembly, it is important to map out what the understanding of sustainability in Stena is like, in order to then measure it with respect to disassembly processes.

CTH has been running concept-map exercises to map sustainability understanding in production research since 2010. The method being adopted to collect and analyze data from concept maps [2] is well-established in the field of sustainability science for engineering

Resultat

In this section, the results will be described according to their classifications presented earlier.

1) Analysis of the Workpieces – Hard Drive Variables

Through the analysis of the collection of hard disk drives (HDD), it was found that HDD variables could be classified under five categories as following:

i. Printed Circuit Board (PCB) connection type

The connection type was found to be an important point in the recycling of PCBs automatically, as variety in the connection types determine the actions to be taken immensely. In this project, two sub categories of connection types were identified, Self-Separable (SS) and Force-Separable

(FS) . SS type connection was defined as the contact connection between a PCB and HDD.

ii. PCB Bolt Features

The second important aspect of PCB removal was found to be related to types of bolts and their respective locations on the HDD.

iii. PCB Removal Surface

This variable describes the gripping point/area for the robot to interact with the PCB.

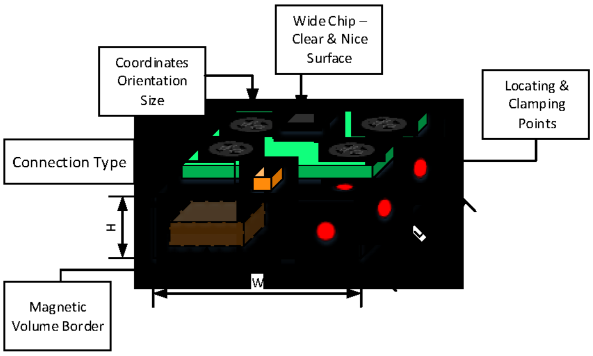
iv. Magnetic Volume Border (MVB)

This variable describes the boundary of the magnetic field generated by the neodymium magnet.

v. Locating and Clamping Points

These variables outline the datum points on the outer shell of HDD with which a fixture is expected to interact.

The following figure illustrates these variables in a typical HDD.

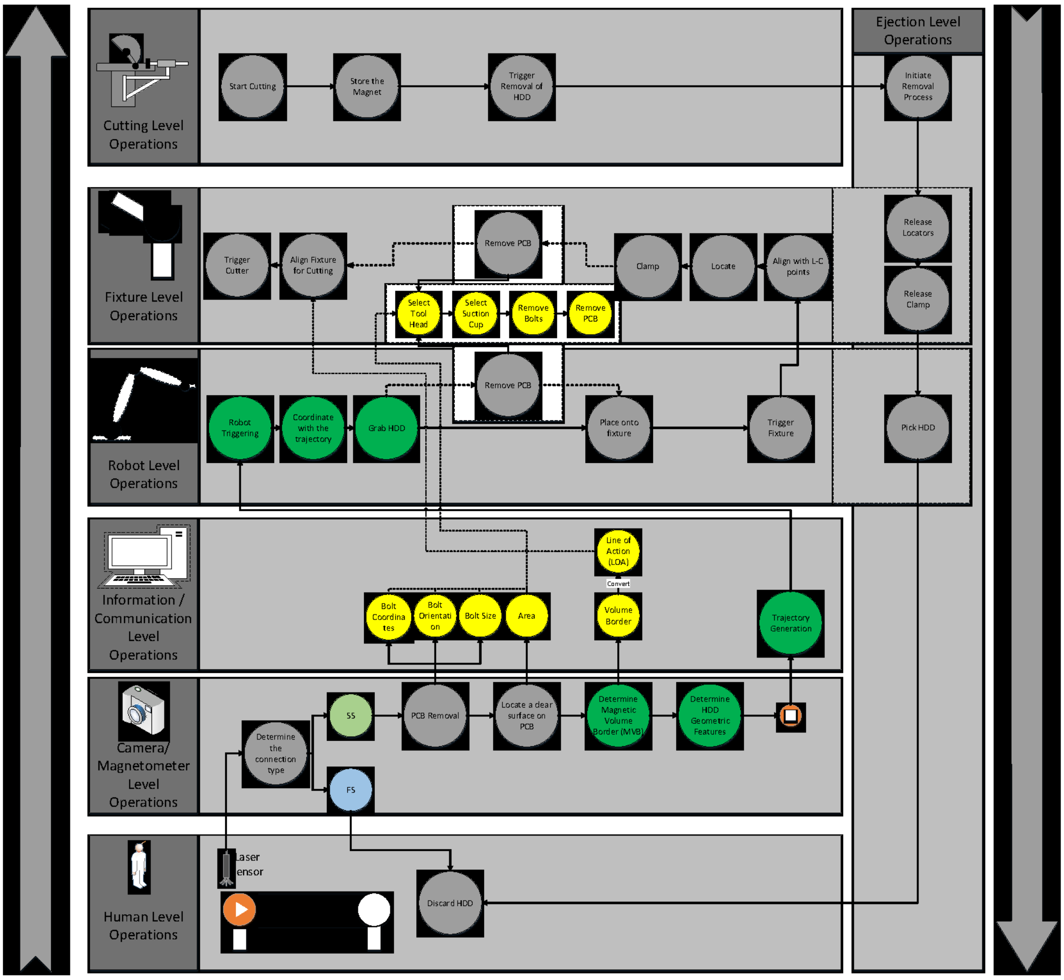


2) Determination of the Technological Capabilities of Individual Resources/Fixtures/Tools.

In order to facilitate the integration of automation and intelligence tools seamlessly, an initial process flow was designed. This process flow mainly builds upon the existing process and outlines how the variables can be integrated efficiently. In this process flow, seven operational levels are suggest which incorporate various operations described as below:

i. Human Level Operations
    a. Feeding
ii. Camera/Magnetometer Operations
    a. Determine PCB connection type
    b. Determine MVB
    c. HDD Size/Geometry
iii. Information/Communication Level
    a. Interpret PCB features
    b. Interpret MVB
    c. Generate a trajectory for robot
iv. Robot Level
    a. Coordinate transformation
    b. Grabbing HDD
    c. Remove PCB (optional)
    d. Position HDD in the fixture
    e. Trigger the fixture
v. Fixture Level
    a. Align/Locate HDD
    b. Secure the position
    c. Remove PCB (optional)
    d. Prepare for removal/transmit locational information
vi. Cutting Level
    a. Initiate cutting
    b. Remove the magnet
    c. Trigger ejection level
vii. Disposal Level
    a. Release locators
    b. Release clamping
    c. Release HDD

The aforementioned suggested workflow is also illustrated in the following figure.



The specific functional requirements are directly correlated to the technological capabilities of the respective resources, fixtures and tools.

3) Control Aspect Using Artificial Intelligence and Digitalization & Demands on the Digitalization Platform

On the overall level, there needs to be a main computer frame that exhibits a close performance to real time and allows flexible programming. This means that a central control platform that can build an interface to product life-cycle management software (i.e., DELMIA, Siemens, AutoDesk) along with the individual controllers of resources in the cell (i.e., Programmable Logic Controller) plays an essential role in establishing a quality-oriented process. Currently, these demands are generally satisfied by commercially available software such as MATLAB and LabVIEW. These platforms can easily establish a contact between both interfaces and is heavily utilized in automotive industry for same purposes.

Not only their interface capabilities, but also their real time sensor data acquisition capabilities qualify these platforms as perfect candidates for synthesizing digitalization and artificial intelligence, without compromising the robustness of the automation.

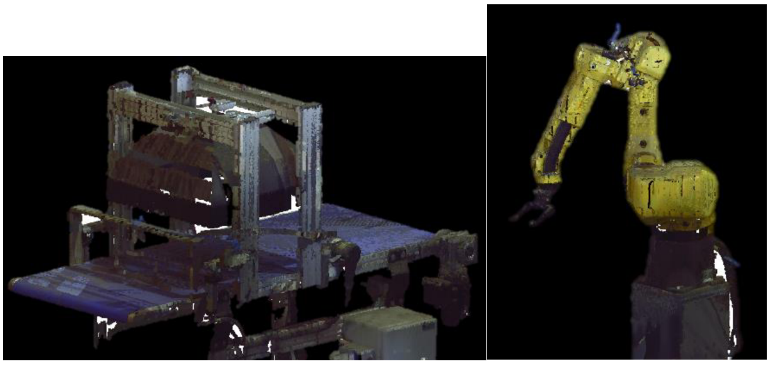
4) Design, Development & Physical Implementation of Findings into the Robotic Cell

a. The New Layout Functions

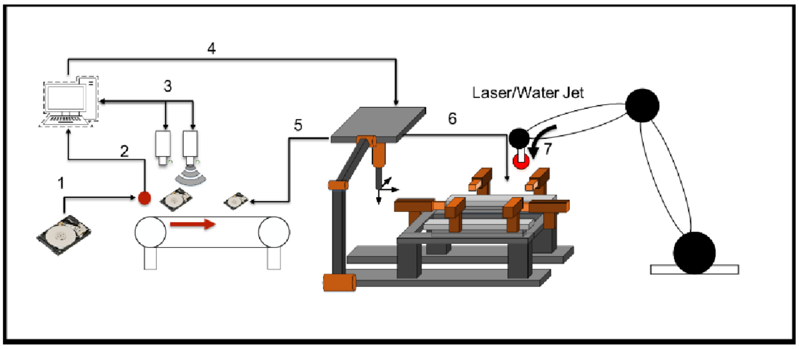
By using the proposed process flow, a new flexible fixture was designed. Moreover, the existing resources are redistributed in a new cell layout to fulfil the requirements of a digitalized recycling process.

The proposed cell layout utilizes certain existing resources (illustrated in the following figure) namely

- A conveyor belt for human level operations,
- A camera, magnetometer and digitalized platform
- 6-axes articulated robot.

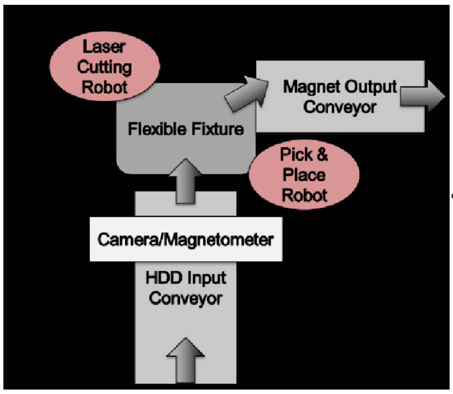


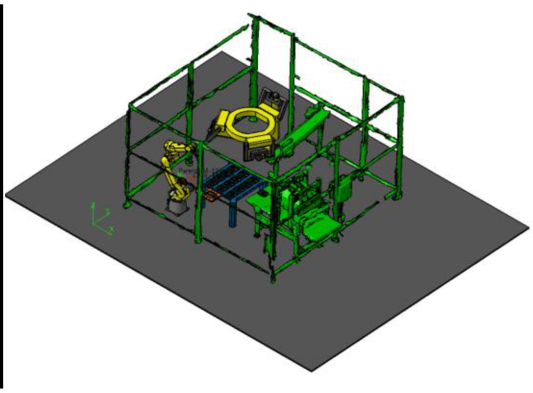
Furthermore, the new layout introduces a pick-and-place robot and a new flexible fixture to robustly locate and enable quick and accurate positioning of the workpieces. Therefore, this removes the need of cutting through a saw and introduces more sophisticated and flexible cutting operations, such as laser and water jet cutting. The new functional layout is drawn in the following figure.



b. The Layout Design

The proposed layout was designed by relocating the existing resources. The main functionalities of the existing setting was aimed to be preserved. The new layout is designed according to the figure below.



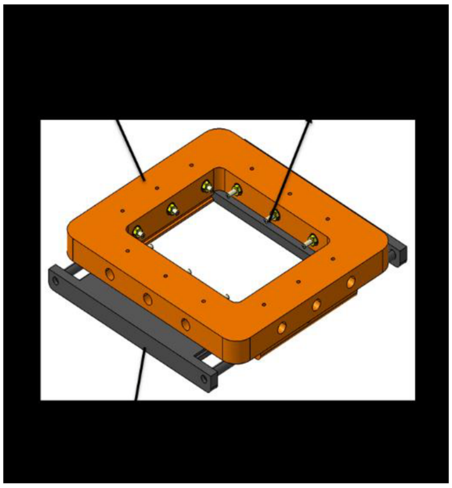


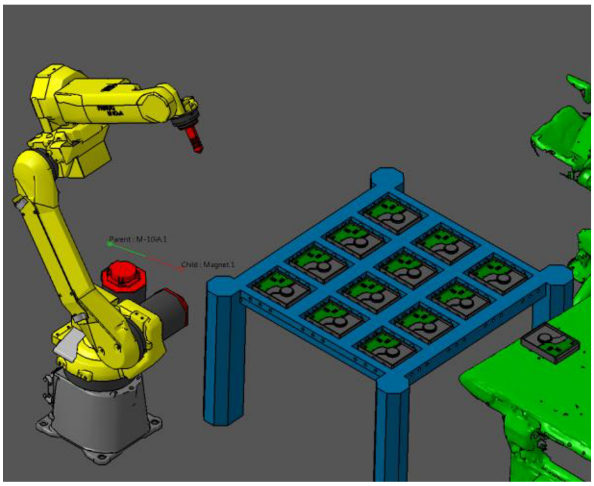
c. The Proposed Fixture

The flexible fixture is designed to handle different variations in HDDs by using the variables analyzed in the analysis section. Mainly, the flexible fixture consists of:

- Pneumatically activated locating pins
- Frame with linear measurement encoders to determine the final position and orientation of the workpiece
- Locating and removal surface to enable laser cutting

The designed single and multi-fixtures are illustrated in the following figure.





5) The Method for Digital Extraction and Evaluation of the Information

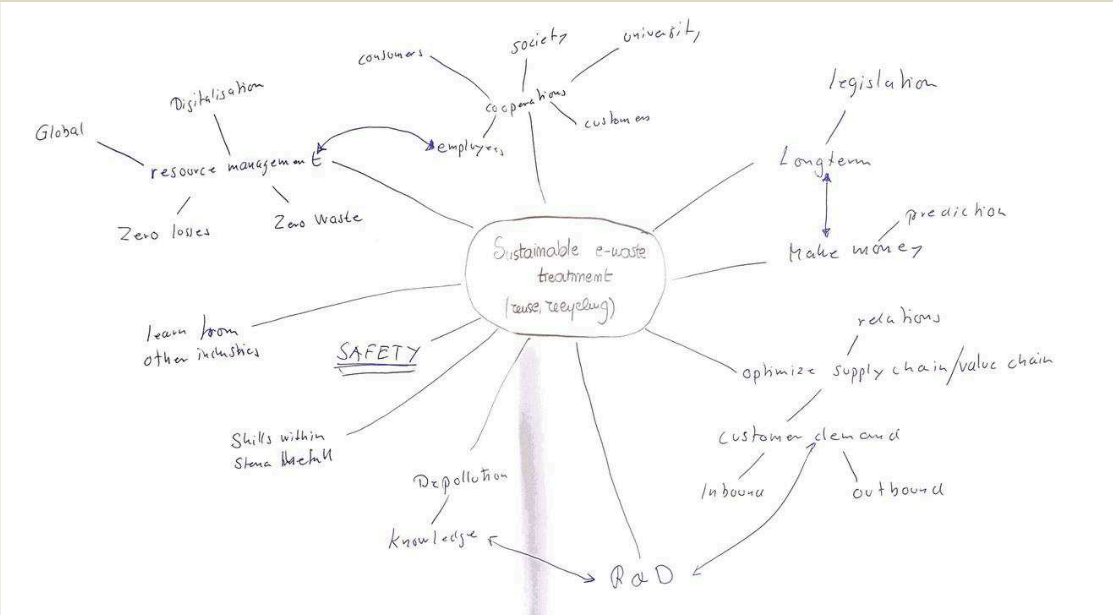
The main idea of digital extraction relies on the development of the respective resources integrated with sensors, whereas the type of sensors depends on the objectives. For recycling HDDs, the main objectives are: enabling flexibility and measuring sustainability process performance.

Flexibility was provided by integrating the positon and magnetic sensors into the resources. Furthermore, an evaluation through the digital platform has been created where information about variations, such as bolt coordinates and magnetic volume border, is transformed into resource actions. This can be easily achieved by means of software platforms discussed earlier.

Environmental and economical sustainability metrics can also be integrated into the new cell layout and constantly evaluated in order to reduce the environmental impact of the recycling process. This is an important example of how flexibility can be utilized to facilitate more sustainable recycling processes. An example of such can be seen in the optimization of trajectory generation to reduce the process time and energy consumption in HDD recycling. Furthermore, by integrating more flexibility in the fixture, multiple product types can be incorporated into recycling process.

6) Sustainability analysis: a stakeholder outlook

The method being adopted to collect and analyze data about sustainability understanding of the process owners was concept mapping. The participants of the exercise are asked to draw concepts around a central one, which in this case is: "What is sustainable e-waste treatment? (reuse, recycling)". Then, the participants connect them as they see fit in their own "mental model". The concept map in the figure below resulted from a participant in the WEEE Digit project.



From the analysis of the concept maps, it emerged that:

- Sustainability is seen in its four pillars: economy, environment, society and institutions.
- The concept of sustainability as seen by the involved stakeholders has a product-life cycle view and multi-stakeholder view embedded (given by

concepts such as “supply chain” and “value chain”, “employees” and “consumers”).

- KPIs for measuring economic impacts of the flexible-feature technology are: return of investment and total cost of ownership, among others.
- KPIs for measuring environmental impacts of the flexible-feature technology are: saved resources across the product’s life cycle, saved CRM and shorter “waste-to-product” cycles.
- The concept of “Safety” stood out, and it is considered to be a prominent driver for increased automation in pre-treatment and disassembly processes in the e-waste recycling industry.
- Following the aforementioned point, the number of injuries, work-related sick leave and employee wellbeing are suitable KPIs to track safety improvements brought by the adoption of robust automation in pre-treatment processes.
- Distinction between physical automation and digitalization, where the latter enables the storage of product-and-process information to be converted into knowledge. Such an outcome would make automation and digitalization gain momentum in the e-waste recycling industry.

A semi-structured interview has been carried out in order to ascertain what Stena Metall’s value proposition, strategic direction and challenges are. The interview protocol being used in WEEE Digit has been previously used in several interviews carried out with top and middle managers in the manufacturing industry. The interview questions are available at [3]. The three points below consolidate the main findings:

- Robust, industrial automation and digitalization will be pervasive not only in pre-treatment processes for e-waste disassembly, but within the whole reverse logistics. These are deemed prerequisites to drive a smarter and more effective resource management, which is Stena Metall’s core competence.

- Product end-of-life treatments will be supported by automated decision-making tools. The decision of “reuse”, “refurbish”, “disassemble” and “shred” will be taken automatically by software and operated by robots according to the workpiece being handled and its conditions.

- One of the roadblocks to increased automation and digitalization in the e-waste recycling industry is the actual possibility to saturate the plant with enough workpieces, in order to justify the investment in equipment and R&D. Paying such investment off might require reconsidering centralization of facilities for e-waste treatment and material flows across borders.

Once the developed robotic cell is realized and deployed, it is necessary to map how material and information flows in the facility change and what the resulting sustainability impacts are in comparison to the previous state of the facility (prior to the deployment). Several system configurations (e.g., cell layout and facility layout, inbound and outbound logistics) have to be evaluated by means of the sustainability KPIs, used as decision-making criteria. Visualizing the value of such KPIs gives decision stakeholders, such as facility managers and technical specialists, information to select the decision which is mostly aligned with the company strategy. The figure below illustrates a high-level methodology to analyze sustainability impacts of the robotic cell. Such a methodology derives from a previous project on WEEE sorting aided by automation solutions [4,5].

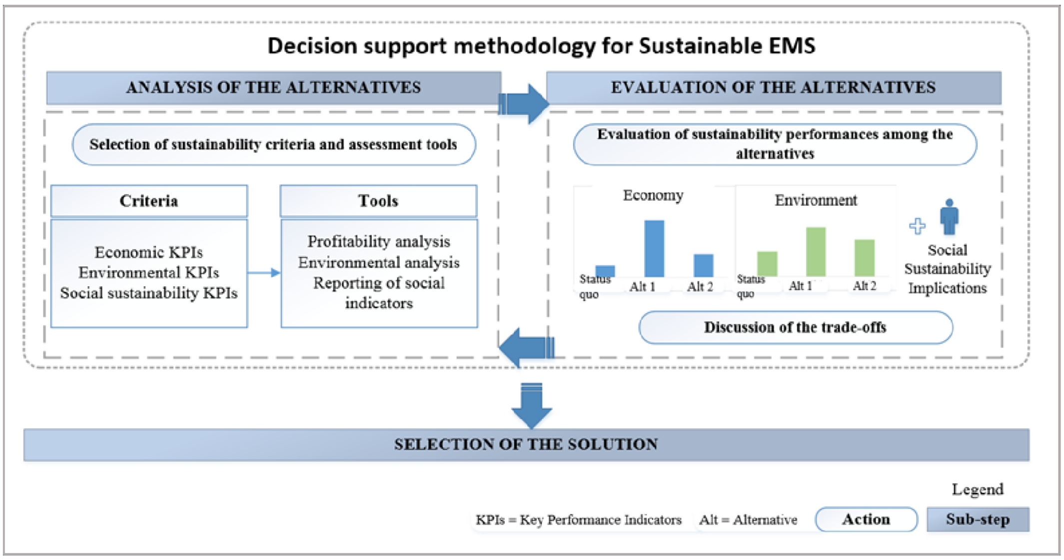


Figure: Decision support methodology to enable sustainable e-waste management systems (EMS). From [5].

7) Workshop

During the 13th of December 2017 a workshop was arranged with around 30 participants from 10 organizations working on recycling. The purpose of the workshop was to showcase how virtual tools can be used during the design and operations of recycling processes. Both discrete and continuous process were discussed and showcases with real industrial cases from battery sorting, mining, car dismantling and digital platforms which can be of use was demonstrated. An effort towards the upcoming call from RE:Source which is planned for summer 2018 was discussed, where it might be possible to apply for additional research funding to develop those tools more towards recycling industries.

Diskussion

Firstly, the main indication of the results achieved through this project indicate that the technologies designed for flexibility and reconfigurability are very suitable for recycling industries. With the age of digitalization, these technologies can easily be integrated into recycling as demonstrated virtually in deliverables D2, D3 and D4.

Moreover, the digitalization can further enable the mitigation of losses in the recycling process; making it more efficient in terms of environmental and financial aspects. Particularly, with the integration of software platforms that are capable of interpreting the measured sensor data, concepts such as optimization and adaptability can be further elaborated in order to reach the desired sustainability goals.

Thirdly, with the support of digitalized flexible technologies process quality can be drastically increased. This suggests that manufacturing industries' need for raw material can be supplied if further advancements are made by advanced and long-term research projects. Consequently, a possible impact on the society becomes an achievable goal.

Referenser, källor

[1] (EU FP7. NMP 2012.4.1-2 Innovative recycling technologies of key metals in high-tech applications. EU project number 310240; *REMENACE: Rare Earth Magnet Recovery for Environmental and Resource Protection.)*

[2] Segalàs J, Ferrer-Balas D, Mulder KF. Conceptual maps: measuring learning processes of engineering students concerning sustainable development. European Journal of Engineering Education. 2008;33(3):297-306.

[3] Barletta I. Interview questions for eliciting core capabilities and the strategy adopted for sustainability in manufacturing companies [Internet] Chalmers Publication Library (CPL); 2017. https://publications.lib.chalmers.se/publication/252161-sustainable-manufacturing-strategy-and-capability-maturity-interview-questions

[4] Chalmers. Knowledge and technology for more sustainable e-waste recycling (WEEE ID). https://www.chalmers.se/en/projects/Pages/WEEE-ID.aspx

[5] Barletta I, Larborn J, Mani M, Johansson B. Towards An Assessment Methodology to Support Decision Making for Sustainable Electronic Waste Management Systems: Automatic Sorting Technology. Sustainability. 2016;8(1).

Bilagor

- Administrativ bilaga (se mall) (OBLIGATORISK)
- Avhandlingar 2 st kommande, ej klara i dagsläget.

  En hösten 2018 samt en 2019.