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AN ENVIRONMENTAL MANAGEMENT INFORMATION SYSTEM TO SUPPORT THE DECISION-MAKING PROCESS IN THE RECYCLING SECTOR FOR END-OF-LIFE-VEHICLES

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Abstract

In recent years, legal and social pressure increasingly forces companies operating in the recycling sector to take into account environmental aspects. For automobile recyclers, especially statutory provisions such as recycling and reuse quotas, are a challenging factor and consequently compels them to include the arising ecological requirements into the decision-making. To support practitioners in the evaluation and selection of alternatives in the context of the recycling process of end-of-life vehicles (ELV), we design and evaluate an environmental management information system (EMIS). The development of the proposed system is based on an acknowledged design science approach. Therefore, we determined industry-specific requirements and source systems of information and embed them into the system architecture. Finally, we show the suitability of the proposed EMIS based on a real-world case study in the recycling sector of ELVs and point out its benefits with respect to economic and environmental aspects. To sum up, the proposed EMIS demonstrates the integration of internal and external data sources as well as legal requirements and voluntary ecological aspects to provide a basis for reasonable decision-making applications in the context of ELVs.

Keywords: Environmental Management Information System, Recycling Sector, Sustainability, Design Science, Green IS.

1 INTRODUCTION

In the past decades environmental issues became more and more important due to natural scarcity, increased awareness of customers and social as well as legal (environmental) pressure. These factors have a considerable influence on decisions in enterprises and hence led to a rethinking and adaption of traditional decision-making processes to the arising sustainable requirements. For this reason, the economic sustainability has to be extended by an environmental as well as societal dimension (Dyllick & Hockerts 2002). The principles of a sustainable development take into account the needs of present as well as future generations in order to enable the realization of a better life (Brundtland 1987). This goes in line with the concept of the 'triple bottom line', defining sustainability as an integration of economic, ecological and social dimensions into strategic decision-making (Elkington 1994; 1997). Due to an overall development towards more sustainability in business organizations, especially the recycling of end-of-life products became popular. In this context, waste streams with strict legal requirements and regulations such as end-of-life vehicles (ELV) are of increasing interest and force enterprises to act in a more efficient way. This includes, for example, decisions with respect to vehicle routing, network (re-) design, recycling systems and technologies as well as processes.

In order to cope with the stated challenges of sustainability in the recycling sector for ELVs, the use of an appropriate information system (IS) is an important factor (Chen et al. 2008; Kurnia et al. 2012; Stiel & Teuteberg 2013) due to its significant influence on the management of sustainable business processes (Seidel et al. 2012; Vom Brocke & Seidel 2012; Watson et al. 2010). Despite the arising benefits e.g. cost reduction and risk avoidance (Erek et al. 2009), "the synergy between environmental management and information systems has not yet been realized to the extent which is possible" (El-Gayar & Fritz 2006). Hence, the need for "IS-enabled organizational practices and processes that improve environmental and economic performance" (Melville 2010) becomes obvious.

A reasonable way to support a sustainable decision-making process in the recycling sector of ELVs is the introduction of an Environmental Management Information System (EMIS). The suitability of an EMIS in the context of (sustainable) supply chain management and reverse logistics was already demonstrated (Stindt 2014; Stindt et al. 2014). Since the recycling sector for ELVs has to face particular challenges, a managerial decision support system which gathers, processes and distributes sector-specific environmental data, explicitly addressing the specifications of this specific waste-recycling sector has to be developed. Therefore, we focus on the following research question:

How can an Environmental Management Information System be conceptualized and designed to support the decision-making process in the recycling sector for end-of-life-vehicles?

The presented research provides a promising approach to support decision-making in the recycling process of ELVs by providing an overall concept of an EMIS incorporating necessary economic as well as environmental data. This leads to a better integration of relevant ecological aspects into the business processes and decision-making in this specific recycling sector. In doing so, mattering components, information and data are identified, structured and considered in the design of the proposed EMIS. The development of the presented system architecture is based on the design science paradigm (Hevner et al. 2004; Peffers et al. 2007), a well-acknowledged research methodology in IS.

The remainder of the article is structured as follows: In section 2, we describe the concept of an EMIS for the recycling sector of ELVs and point out the motivation for an appropriate approach. The detailed description of the underlying research methodology follows in section 3. In section 4, the developed EMIS is introduced and the architecture is described in depth. Thereafter, we demonstrate the suitability of the presented approach by means of an application case in section 5. Finally, a conclusion is drawn, key findings are summarized and ideas for future research are presented.

2 THE WAY TO A MORE EFFICIENT AND SUSTAINABLE RECYCLING SECTOR FOR END-OF-LIFE VEHICLES

Developments in recent years forced the recycling sector to cope with a set of emerging challenges and requirements. On the one hand, increasing external pressure of different stakeholder groups is put on recycling companies and pressurizes them to include economic, ecologic and social aspects into the companies' processes and decisions. On the other hand, directives and legislations concerning the prevention and recycling of waste streams, the compliance with thresholds of recyclability and recoverability rates force them to improve their processes in a more efficient and more sustainable way. Especially the recycling sector for ELVs has to cope with rigorous requirements as ELVs firstly contain several hazardous substances and secondly have a high potential of recyclable components. To efficiently meet the mentioned requirements and to manage the economic and environmental goals, an integration of IS is proposed (Loos et al. 2011). "Computer-based information systems are extensively used in support of environmental management and decision-making in a variety of contexts" (Frysinger 2012). Despite the fact that environmental issues and sustainable performance is increasing, the environmental aspects are often neglected in literature on IS and management (Watson et al. 2012). As management processes in companies are normally assisted by several different information systems, redundant databases or inconsistencies of information and data are the consequence which can be resolved by an EMIS (Frysinger 2012). Moreover, the development of such a system to provide a computer-based support of recycling processes and in particular dismantling processes can lead to economic advantages (Hilty & Rautenstrauch 1997). The concept of EMIS can be defined as "organizational-technical systems for systematically obtaining, processing and making environmentally relevant information available for companies" (Hilty & Rautenstrauch 1997). In this context, it is used inter alia for detecting environmental impacts, planning, managing and monitoring environmental measures, supporting the preparation stage in the decision-making process by selection of alternatives (Moore 2002; Teuteberg & Marx Gómez 2010) as well as for providing information concerning environmental impacts of products or processes to meet external requirements (Rautenstrauch & Patig 2001, pp. 5-6) and legal provisions.

Although, the use of an EMIS may lead to certain benefits, e.g. time-saving or cost reduction (Mock & Schroeder 2002) in addition to compliance with legal requirements and meeting external demands, literature on EMIS is rare (Simmonds & Bhattacherjee 2012). El-Gayar & Fritz (2006) present a conceptual overview of EMIS. A survey focusing on the requirements of an EMIS and first conceptual implications are conducted by Gräuler et al. (2013). An EMIS for the Energy Sector has been developed by Nuss (2015). Stindt (2014) present a generalized EMIS for decision-making in reverse logistics. Moreover, Stindt et al. (2014) developed an artifact and evaluated the suitability based on a real-world case study in the electronics industry. Nevertheless, the proposed systems cannot be transferred to the ELV sector as product complexity is comparatively high and the recycling process and in particular the dismantling process is relatively complicated (Hilty & Rautenstrauch, 1997), hence sector and process specific characteristics cannot be taken into account. To the best of our knowledge, information technology (IT) solutions for a systematic integration of environmental information and its effects on the recycling process of ELVs as well as the preparation of relevant environmental data for stakeholders in this sector by means of an EMIS has not been considered in literature yet.

The presented EMIS supports practitioners in the decision-making process by collecting and administrating relevant economic and ecological data for the ELV recycling process which originate from diverse sources and consequently by providing appropriate data and consequently a basis for applications within the decision support system. Furthermore, it enables the provision of reasonable information according to the requirements of the different groups of stakeholders.

3 RESEARCH METHODOLOGY

In order to answer the stated research question, the 'applied design science research model' (Bensch 2012; Stindt 2014; Stindt et al. 2014) is adopted (*Figure 1*). This model is a combination of the 'design science research methodology process model' (Peffers et al. 2006; Peffers et al. 2007) and the guidelines for design science (Hevner et al. 2004). Since the identified problem is a real-world business problem, the design science approach is suitable (Hevner & Chatterjee 2010) as "it focuses on creating and evaluating innovative IT artifacts that enable organizations to address important information-related tasks" (Hevner et al. 2004). Moreover, it has been shown that the paradigm of design science is suitable in similar contexts (Stindt et al. 2014; Stindt 2014; Nuss 2015). In the following, the implementation of this generic approach to the research at hand is presented.

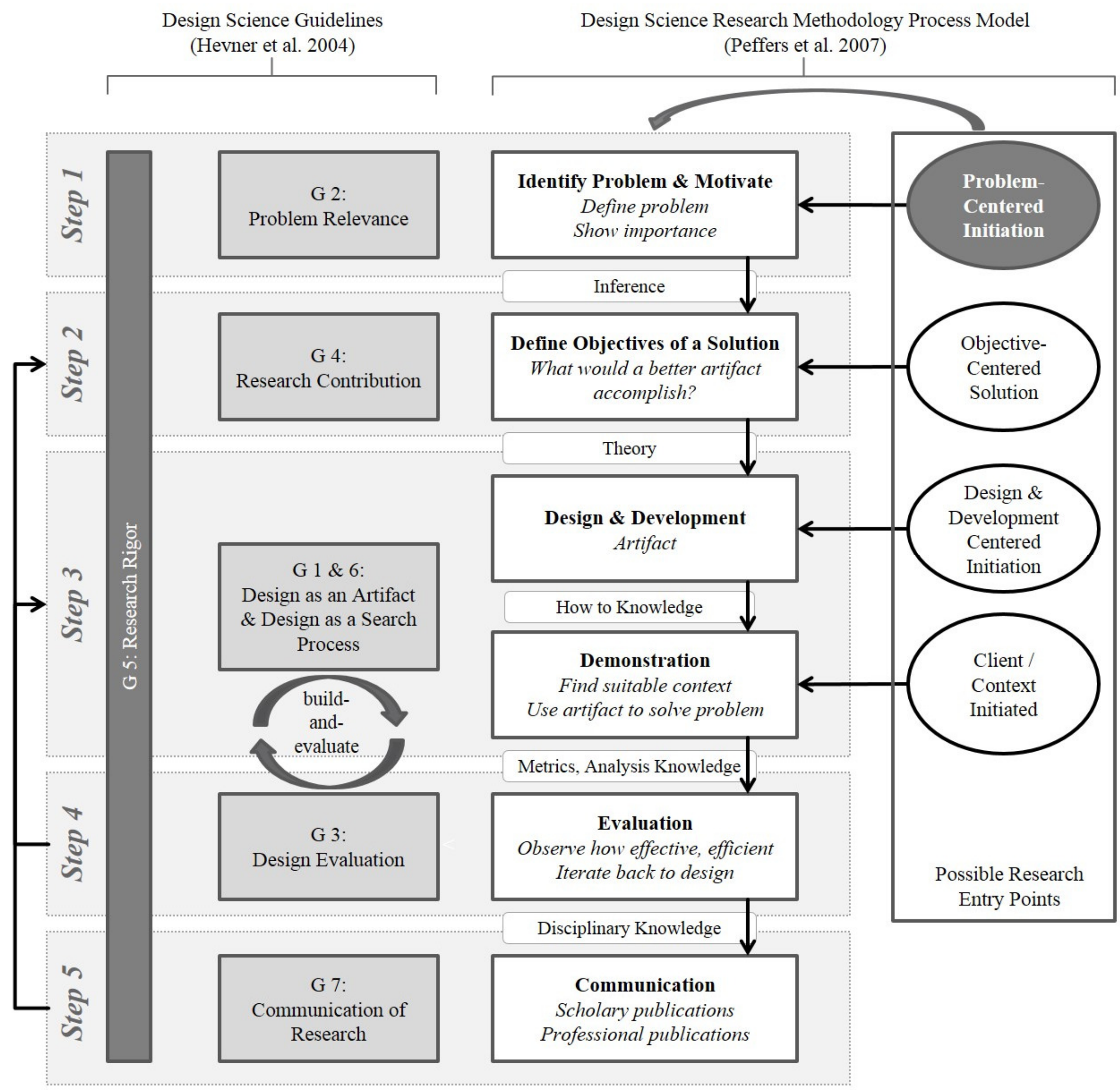

Figure 1. Applied design science research model based on Bensch (2012), Peffers et al. (2007), Hevner et al. (2004), Stindt (2014) and Stindt et al. (2014).

Step 1– Identify Problem & Motivate

As there is a need for an integration of environmental aspects into the decision-making process in the recycling sector for ELV, we selected a problem-centered initiation as a research entry point (in reference to Peffers et al. (2007)). The guideline 'problem relevance' (G2) refers to "the development and implementation of technology-based solutions to heretofore unsolved and important business problems" (Hevner et al. 2004, p. 84). As mentioned above our research is based upon problems which can be found in both literature and practical cases (G2). Consequently, the presented artifact, i.e. a strategic EMIS for a sustainable decision-making in the context of recycling of ELVs, expands the knowledge base and addresses the challenges of real-world business problems. To the authors' knowledge, this kind of system is currently missing in academia as well as practice.

Step 2 – Define Objectives of a Solution

In accordance with the stated research question, we aim to develop an EMIS that supports the decision-making process in the recycling sector for ELVs with an environmental-oriented focus. The developed artifact intends to support and improve the practical applicability of quantitative decision-support models for the recycling of ELVs. This leads to an expansion of the current level of knowledge as it closes a gap in research between EMIS and operations research through an integration of these topics (G4).

Step 3 – Design & Development

The proposed EMIS represents the prepared artifact (G1). The conceptual design of the EMIS is presented in detail in section 4. In doing so, we revert to established reference architectures and approaches with a sustainable focus (Hevner et al. 2004; Stindt 2014; Stindt et al. 2014; Teuteberg & Marx Gómez 2010) (G6). The description of the three layers addresses sector-specific characteristics as well as certain requirements of the underlying recycling process which are laid down on an EMIS for the recycling sector for ELVs.

Step 4 – Demonstration & Evaluation

For the development of an effective EMIS, a step-by-step process with an alternation between the construction of the artifact (Step 3) and the evaluation of its performance (Step 4) is accomplished ('build-and-evaluate'). This procedure was already suggested by e.g. March and Smith (1995) and Hevner et al. (2004). In doing so, the suitability of the presented EMIS to support decision-making in the context of ELVs is demonstrated by an evaluation setting which is based on real-world data from industry insiders as well as on data derived from secondary sources, such as public databases (G3).

Step 5 – Communication

By means of the presented article, the results and key findings of our research are summarized and hence communicated to the academic IS community (G7). Furthermore, we propose an EMIS to support the decision-making process in the recycling sector for ELVs by identifying relevant data and information in this context, demonstrating the connection of EMIS and decision-making and therefore provide a basis for practitioners to extend existing or design new systems.

As acknowledged methods and techniques originated from IS, operations research as well as management sciences are used throughout the research process, the requirements of the Research Rigor (G5) are consistently met.

4 CONCEPTUAL MODEL OF AN EMIS FOR ELV RECYCLING

The structure of the proposed EMIS is based on reference architectures for such systems (Stindt 2014; Stindt et al. 2014; Teuteberg & Straßenburg, 2009; Freundlieb & Teuteberg, 2009) and is extended to meet the requirements of the recycling process of ELVs as well as to consider industry-specific characteristics. The architecture of the EMIS is described in the following. Thereby, a special focus is on the three-tier layer structure, the involved systems and the resulting interdependencies and data flows. An illustration of the proposed EMIS architecture is presented in *Figure 2*.

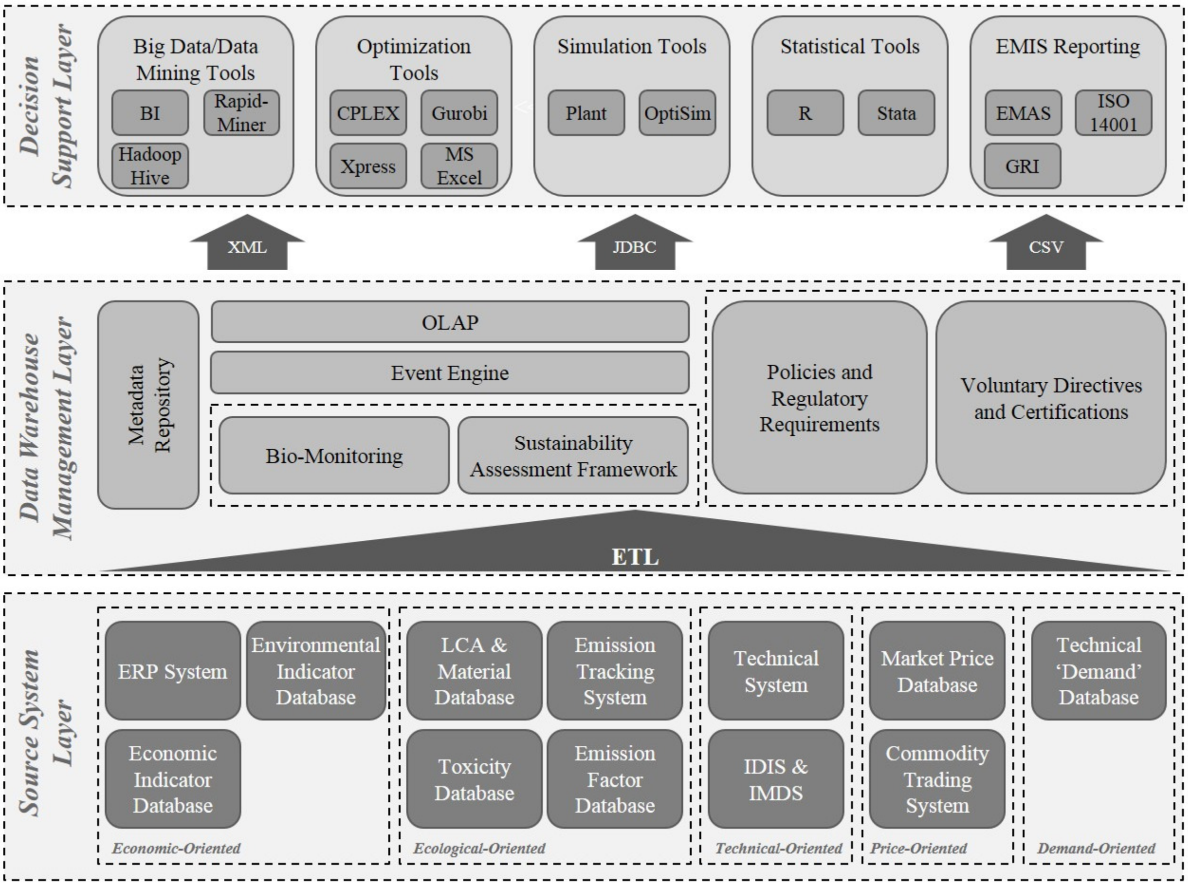

Figure 2. Architecture of the proposed EMIS following Stindt (2014) and Stindt et al. (2014).

4.1 Source System Layer

The source system layer represents the part of the proposed architecture where all relevant information is integrated into the EMIS. Due to the special characteristics of recycling networks, and in particular for ELVs, traditional economic data is insufficient and need to be extended by several data, especially concerning environmental aspects. In order to cope with the arising information requirements, both external and internal source systems need to be integrated into the EMIS (Gräuler et al. 2013; Mock & Schroeder 2002). Nevertheless, this system integration can be a challenging task.

Based on previous works (Stindt 2014; Stindt et al. 2014) and information from industry insiders and experts, in the following we enriched the therein included parts of the source system layer by further industry-specific information as well as additional databases and systems which are more suitable for ELV recycling. The identified data sources can be clustered in economic-, ecological-, technical-, price- and demand-oriented system components.

The economic-oriented part of the source system layer contains three modules. Existing Enterprise Resource Planning (ERP) systems provide traditional economic data. This information include amongst others revenue, sales structures and cost data which encompasses structures regarding general costs, dismantling, working processes, transportation and procurement. In this context, the used raw materials and the corresponding quantitative composition data and hence the physical composition and quality are of particular interest. For a well-founded forecast of future return flows of ELVs, adequate statistical methods, e.g. a regression, are necessary. In doing so, several economic as well as environmental data is necessary. Information with an economic focus can be extracted from public economic indicator databases, such as Eurostat (Europe) or Destatis (Germany). Environmental data which directly influence the amount of return flows e.g. waste generation and in particular of ELVs, can be extracted from environmental indicator databases.

Environmental data can be extracted from the ecological-oriented component of the EMIS containing toxicity databases, emission tracking systems, emission factor databases and Life Cycle Assessment (LCA) & Material databases. For information regarding the toxicity of substances and materials resulting from the recycling process, toxicity databases are used. The Toxic Release Inventory prepares data with respect to emergence of chemical substances and their toxic properties. The eChemPortal, i.e. Global Portal to Information on Chemical Substances, is connected to several international toxicity databases, such as the European Chemicals Agency (ECHA) database, and provides information on (hazardous) characteristics of chemical substance. For the determination of carbon dioxide emissions, emission tracking systems which are installed in the recycling company may provide information. The individual recycling processes of ELVs often takes place in recycling companies where several different recyclable materials and wastes are processed and hence technical assets are installed in order to meet mandatory emission thresholds. Consequently, data relating to emissions resulting from the treatment of ELVs can be tracked and extracted from the corresponding systems or databases. Otherwise, databases, such as Intergovernmental Panel on Climate Change (IPCC) Emission factor database and International Emission Factor Database provide comprehensive information and data of CO_2-emissions resulting from certain process steps. LCA & Material databases include detailed information concerning the material composition (e.g. chemical and physical) of products and components as well as data concerning certain processes and by-products and several dimensions of environmental effects, e.g. resulting from transport and disposal. The most extensive databases (primarily focusing on process-based basic data) are ecoinvent Database, ProBas, GaBi Database and US Lifecycle Inventory Database.

The International Material Data System (IMDS) and International Dismantling Information System (IDIS) represent the technical-oriented component and are industry-specific systems providing information of the automobile sector. The IMDS offers data of modules, (semi)components, materials and basic substances which are installed in certain automobiles. The IDIS focuses on specific information for the depollution and dismantling process of ELVs. Moreover, it contains inter alia specific details depending on the different car model of concerning types of material, weight, number and position of build-in components as well as recommended technical systems and tools for the respective depollution and dismantling processes. Technical systems which are nowadays often installed in recycling companies provide information about the capacity utilization of the different recycling and processing systems. An integration of these systems into the EMIS enables a coordination of recycling processes with other recycling activities which are executed in the mentioned companies in an environmental advantageous way.

The price-oriented system component contains two modules. The market price is depending on the different types of products resulting from the recycling process. The prices for reusable parts, i.e. used and checked components which are dismantled from the ELVs can be extracted from respective databases (market price database). The scrap metals, e.g. ferrous scrap (steel) and non-ferrous scrap (e.g. aluminum, copper, zinc, lead) are traded at the commodity exchange and metal exchange. Furthermore, prices for certain products (e.g. plastic components) are significantly influenced by the oil price which is also determined by the commodity exchange. Commodity trading systems provide daily market prices for gained materials.

The technical ‘demand’ database gives details concerning the technical (partly mandatory) requirements of the products for the following recycling and disposal processes or sales activities of reusable parts.

4.2 Data Warehouse Management Layer

The data warehouse management layer extracts, transforms and loads (ETL) heterogeneous data provided by internal and external systems as well as different databases from the source system layer. Consequently, it contains and links all relevant data and provides input parameters for analytical reports or analysis for decision support systems. The metadata repository is a central part of the data warehouse management layer and includes information with respect to the data which are extracted from the mentioned databases and systems. To support subsequent analysis and reports, requirements resulting from policies and regulatory requirements as well as voluntary directives and certifications are important components of the EMIS. In the former context, for instance target quotas relating to reuse, recycling and recovery of ELVs and their components (Directive 2000/53/EC) and thresholds for air polluting emissions (especially CO_2) as well as thresholds or rather target values (e.g. for heavy metals such as lead, mercury, nickel and cadmium) provide further data. Moreover, voluntary directives such as VDI (Association of German Engineers) directives and certifications, e.g. a certification according to ISO 9001 (i.e. standard for quality management systems) complement the data.

A further component of the data warehouse management layer is the sustainability assessment framework supporting the reporting process concerning sustainability measures and the collection of the therefore required data (Ahmed & Sundaram 2007). In doing so, "indices, composite indicators, or aggregate values are used to simplify high dimensional and complex data sets and to clarify assessment results" (Pollesch & Dale, 2015). An overview of frameworks for assessing sustainability is presented by Singha et al. (2012), Ahmed & Sundaram (2007) and Labuschagne et al. (2005). For the control of air pollution caused by the recycling process, a bio-monitoring module is included. A periodical taking and analyzing of water and soil samples enables the determination of ecological impacts for the environment, e.g. contamination with heavy metals such as lead, chromium, nickel, cadmium and mercury, arising from the recycling process.

The event engine automatically reacts on violations of environmental restriction or thresholds (such as emission thresholds) by generating reports and alerts in order to trigger the appropriate workflows and measures (Freundlieb & Teuteberg 2009; Teuteberg & Marx Gómez 2010). The online analytical processing (OLAP) as a central component of the data warehouse management layer enables the processing of the multi-dimensional data derived from the different systems and databases of the source system layer in a structural manner and provides them in the required granularity for the applications of the decision support layer.

4.3 Decision Support Layer

In the context of automobile recyclers, decision-making may comprise problems with respect to emission- and energy-efficient recycling processes, ecological vehicle routing, network design decisions, recycling systems and technologies. The decision support layer is connected with the data warehouse management layer through standardized data formats (e.g. XML, CSV). Furthermore, adequate tools for Big Data and Data Mining (e.g. Business Intelligence (BI), RapidMiner), optimization (e.g. CPLEX, Gurobi), simulation (e.g. Plant, OptiSim) and statistical analysis (e.g. R, Stata) are embedded within this layer to provide a software-based support for the decision-making in the recycling sector for ELVs. Automobile recyclers increasingly experience pressure to meet standards for environmental management, such as the Eco-Management and Audit Scheme (EMAS), ISO 14001 certification (El-Gayar & Fritz 2006) and Global Reporting Initiative (GRI) guidelines as well as to provide sustainability-reporting to stakeholders (Erek et al. 2009; Fernandez-Feijoo et al. 2014). To meet the mentioned requirements, the decision support layer of the presented EMIS provides a reporting component for the creation of reports to support compliance with environmental regulations and to prepare stakeholder information.

5 EVALUATION

The recycling sector for ELVs has to cope with different planning problems related to the recycling process, the network structure as well as transportation. An overview of relevant planning tasks in this context is given by Nuss et al. (2015). Each planning problem requires certain problem relevant information which are provided by the respective data sources which are in most cases only a subset of the integrated external and internal source systems. Consequently, not all databases and systems of the source system layer are needed for each problem. To show the suitability and value of the presented

EMIS, we exemplarily analyse one planning problem arising in this particular recycling sector and point out how the EMIS at hand can support the decision-making process, i.e. if necessary data are accessible through the presented system. For this purpose, we identify the required data and show the involved components of the EMIS, i.e. databases and systems, which provide the respective data.

The value of the presented EMIS is demonstrated by means of an evaluation setting which has been inspired by discussions and interviews with industry partners and experts. It is mainly based on real-world data derived from an extensive analysis of the structure of the recycling sector for ELVs and from secondary sources (e.g. public databases). Further intra-sector information of industry insiders and experts completed the data.

Currently, a large interconnected system including collection points for ELVs, dismantling facilities and shredder facilities represent the network. As both economic and ecological benefits may arise from a redesign of the structure of the network, a reconfiguration or rather a review of the general recycling network for ELVs in Germany is conducted. Hence, the network structure for the recycling process of ELVs, amongst others including number and location of dismantling and shredder facilities as well as transport planning has to be determined. The solution of the stated problem is presented in detail by means of a bi-criteria, mixed-integer linear programming (MILP) approach on the basis of the presented EMIS incorporating economic and environmental, and here in particular emission-oriented aspects. Thereby, the EMIS supports the decision-making process by providing the basis of data which are required to tackle the stated problem and hence are necessary input parameters for the following MILP model. Here, the set of parameters can be divided into two classes, namely economic and general parameters (*Table 2*) and ecological parameters (*Table 3*). Additionally, the relevant source systems and databases of the required data are pointed out to clarify the connection between EMIS and decision-making, i.e. to point out how the presented EMIS supports the decision-making process by providing necessary data. The respective index sets are defined in *Table 1*.

I	set of collection points
J	set of dismantling facilities
K	set of shredder facilities
Q	set of components

Table 1. Index Sets.

α	weighting factor for economic goal	–
β	weighting factor for ecological goal	–
$bigM$	sufficiently large number	–
d_{ij}	distance between collection point *i* and dismantling facility *j*	Google Maps, route planning software
d_{jk}	distance between dismantling facility *j* and shredder facility *k*	Google Maps, route planning software
p_q	revenue/costs for component *q* (in €/t)	Market price database, commodity trading system
vc_j^{Dis}	variable costs of dismantling facility *j*	ERP
vc_k^{Shr}	variable costs per unit of shredder facility *k*	ERP
fc_j^{Dis}	fixed costs per unit for dismantling facility *j*	ERP
fc_k^{Shr}	fixed costs for shredder facility *k*	ERP
cap_j^{Dis}	capacity of dismantling facility *j*	ERP
cap_k^{Shr}	capacity of shredder facility *k*	ERP
δ_q	percentage of ELV which results in component *q* (in %)	LCA & material database
λ_q	percentage of stripped vehicle which results in component *q* (in %)	LCA & material database
O_i	ELV arising in collection point *i*	environmental indicator database, economic indicator database, ERP
tc^1	transportation costs for tours between collection point and dismantling facility (€/t*km)	ERP
tc^2	transportation costs tours between dismantling facility and shredder facility (€/t*km)	ERP

Table 2. Economic and general parameters and relevant source systems and databases.

fe_j^{Dis}	variable CO_2-emissions for dismantling facility *j*	emission tracking system, emission factor database
fe_k^{Shr}	variable CO_2-emissions for shredder facility *k*	emission tracking system, emission factor database
te^1	transport emissions for tours between collection point and dismantling facility arising per ton and km	emission factor database
te^2	transport emissions for tours between dismantling facility and shredder facility arising per ton and km	emission factor database

Table 3. Ecological parameters and relevant source systems and databases.

The proposed model includes decisions concerning the activity state of dismantling and shredder facilities i.e. shall the respective facilities remain open or be closed. Moreover, transportation flows regarding ELVs between collection points and dismantling facilities, stripped vehicles between dismantling and shredder facilities as well as components which are sold or disposed by dismantling and shredder facilities are part of the decision (see *Table 4*). The structure of the developed MILP model is presented below.

$\alpha_j \in \{0,1\}$	indicates whether dismantling facility *j* is open
$\beta_k \in \{0,1\}$	indicates weather shredder facility *k* is open
$\gamma_{ij} \in \{0,1\}$	indicates weather arising in collection point *i* are transported to dismantling facility *j*
x_j	amount of ELV arriving in dismantling facility *j*
y_{jk}	flow of stripped vehicles, transported from dismantling facility *j* to shredder facility *k*
w_{jq}	amount of component *q* sold/disposed from dismantling facility *j* (in t)
v_{kq}	amount of component *q* sold/disposed from shredder facility *k* (in t)

Table 4. Decision Variables

To include both economic and ecologic aspects into the decision, we propose a bi-criteria objective function with an economic component, represented by profits and an environmental component, described by CO_2-emissions. The profits take into consideration generated revenues from selling components or reusable materials, expenses incurred for disposal, transportation costs as well as fixed and variable costs for dismantling and shredder facilities. The CO_2-emissions component regards emissions for transportation and the operating dismantling and shredder facilities. To address the trade-off between the two dimensions of the objective function, two weighting factors, namely α and β are introduced. To consider the framework conditions and requirements, several restrictions are stated. A detailed description is given in *Table 5*.

maximize

$$\alpha \cdot \Bigg(\sum_{j\in J}\sum_{q\in Q} w_{jq} \cdot p_q + \sum_{k\in K}\sum_{q\in Q} v_{kq} \cdot p_q - \sum_{i\in I}\sum_{j\in J} x_j \cdot d_{ij} \cdot tc^1 - \sum_{j\in J}\sum_{k\in K} y_{jk} \cdot d_{jk} \cdot tc^2 - \sum_{j\in J} fc_j^{Dis} \cdot \alpha_j - \sum_{j\in J} vc_j^{Dis} \cdot x_j - \sum_{k\in K} fc_k^{Shr} \cdot \beta_k - \sum_{j\in J}\sum_{k\in K} vc_k^{Shr} \cdot y_{jk} \Bigg) - \quad \text{profits}$$

$$\beta \cdot \Bigg(\sum_{j\in J} fe_j^{Dis} \cdot \alpha_j + \sum_{k\in K} fe_k^{Shr} \cdot \beta_k + 2 \cdot \sum_{i\in I}\sum_{j\in J} x_j \cdot d_{ij} \cdot te^1 + 2 \cdot \sum_{j\in J}\sum_{k\in K} y_{jk} \cdot d_{jk} \cdot te^2 \Bigg) \quad CO_2\text{-emissions}$$

subject to:

1	$\sum_{j\in J} \gamma_{ij} = 1$	$\forall i \in I$	all ELVs must be collected
2	$\sum_{i\in I} \gamma_{ij} \cdot O_i = x_j$	$\forall j \in J$	amount of ELV arriving in dismantling facility equals amount of transported ELVs to dismantling facility
3	$x_j = \sum_{k\in K} y_{jk} + \sum_{q\in Q} w_{jq}$	$\forall j \in J$	flow equilibrium regarding dismantling facilities
4	$x_j \cdot \delta_q = w_{jq}$	$\forall j \in J, q \in Q$	flow split into distinct components in dismantling facilities
5	$\sum_{j\in J} x_j \leq bigM \cdot \alpha_j$	$\forall j \in J$	transport only to open dismantling facility

6	$x_j \leq cap_j^{Dis}$	$\forall j \in J$	capacity restriction for dismantling facilities
7	$x_j \cdot \left(1 - \sum_{q \in Q} \delta_q\right) = \sum_{k \in K} y_{jk}$	$\forall j \in J$	defines amount of stripped vehicles
8	$\sum_{j \in J} y_{jk} = \sum_{q \in Q} v_{kq}$	$\forall k \in K$	flow equilibrium regarding shredder facilities
9	$\sum_{j \in J} y_{jk} \cdot \lambda_q = v_{kq}$	$\forall k \in K, q \in Q$	flow split into distinct components in shredder facilities
10	$\sum_{j \in J} y_{jk} \leq bigM \cdot \beta_k$	$\forall k \in K$	transport only to open shredder facility
11	$\sum_{j=1}^{J} y_{jk} \leq cap_k^{Shr}$	$\forall k \in K$	capacity restriction for shredder facilities
12	$x_j, y_{jk,} w_{jq}, v_{kq} \geq 0$	$\forall i \in I, j \in J,$ $k \in K, q \in Q,$ $r \in R$	non-negative condition
13	$\alpha_j, \beta_k, \gamma_{ij} \in \{0; 1\}$	$\forall i \in I, j \in J,$ $k \in K$	binary

Table 5. Restrictions.

6 DISCUSSION AND CONCLUSION

The article at hand presents an EMIS for the recycling sector for ELVs that supports decision-making by providing both economic and ecological data. The proposed artifact is developed based on the design science research methodology and reverts to acknowledged reference architectures which are extended by industry-specific characteristics and requirements. In doing so, we could respond to the stated research question. The architecture of the EMIS is conceptualized based on the identified information requirements concerning economic, environmental as well as legal aspects. For this, data which are necessary for decisions in the case at hand are carved out and appropriate internal and external data sources and databases which are suitable in the context of the recycling sector for ELVs are identified. Furthermore, voluntary measures that are appropriate in this particular environmental context are pointed out.

The presented artifact motivates practitioners to include an environmental perspective into their decisions as it demonstrates factors, information and structures that recycling companies of ELVs may consider in their decision-making. Hence, it provides a system that enables them to include both economic and environmental aspects by providing a basis of therefore necessary data and information as well as regulatory requirements and aspects. To the best of our knowledge, it is the first contribution to IS research in the context of an EMIS with respect to the recycling process of ELVs. It provides an integrated concept for decision support applications incorporating economic and environmental perspectives. We show that the artifact creates a wide basis of information which is relevant for practitioners and researchers in the field of ELV recycling

However, there is still enough potential for future research. The forthcoming spread of electric vehicles in the medium-term will challenge automotive industry as well as recycling companies. On the one hand, this new vehicle generation relieves the environment due to fewer emissions but on the other hand, they contain several components and in particular critical raw materials (e.g. lithium, cobalt and gallium) to an extent which has not been required in the automotive industry until now. Consequently, efficient recycling strategies and processes for electric ELVs and in particular for high-performance batteries, i.e. lithium-ion batteries are necessary to reduce primary demand (Buchert et al. 2011). This challenges automobile recyclers as they may also include material criticality assessments into their considerations and decisions. Another research field may deal with further developments of frameworks for environmental impact assessments. In this context, the detection of possible co-benefits in an environmental and social context involved by e.g. emission reduction may also be an interesting topic.

Summarizing, the presented EMIS enables the integration of environmental aspects into the decision-making processes in the recycling sector for ELVs by addressing industry-specific requirements and framework conditions as well as integrating of appropriate decision support applications.

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