A Business Process Model for the Reverse Logistics of Used Electric Vehicle Batteries

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Abstract: Electric vehicles (EVs) are considered as a ground-breaking innovation for making transportation services more sustainable. Electric vehicle batteries (EVBs) are the major technological components of electric vehicles and account for up to one third of the EVs' initial price. Due to continued cell degradation, EVBs need to be removed from the EVs after some time, but might still be reused in different scenarios such as stationary applications. EVBs that cannot be reused must be recycled to retain valuable materials such as cobalt, lithium, and nickel. The purpose of this paper is to develop a business process model for the reverse logistics of EVBs, transporting them from car workshops to their next usage sites or to adequate recycling facilities. We develop the business process model in a design research endeavor, based on reviewing selected laws and regulations that need to be complied with when transporting high-voltage batteries.

1 Motivation

Electric mobility is supposed to be a key technology to cope with scarce resources and exceeding emissions caused by private and public mobility [Na12]. Powering cars, buses, trains, or motorcycles with electric energy is envisioned to reduce our dependency on fossil energy sources such as oil and might help to eliminate emissions caused by conventional combustion engines, including carbon dioxide, fine dust, and noise [Fe13, Na12].

Electric vehicle batteries (EVBs) are essential components of each electric-driven means of transportation. EVBs are high-voltage power storage devices for supplying the motor of electric vehicles (EVs) with energy. However, for their genuine application in EVs, EVBs become useless over time due to the battery cells' degradation and the growth of its internal resistance [Bu09]. Only replacing an EVB can sustain an EV's maximum performance.

Consequently, used batteries need to be returned back to their vendors or waste management services governed by public law (e.g. §§5 (1), 13 (1) BattG). The treatment of used EVBs is a challenging reverse logistics effort that touches on many ecological, economic, legal, safety-related, and technical issues. Anecdotal evidence suggests that many of the existing reverse logistics processes do not conform to these challenges in the EVB domain.

The purpose of this paper is to identify legal requirements that govern the reverse logistics of used EVBs in Germany, based on which a business process is designed. In a design science approach, a business process model is developed and evaluated in an expert interview based on a subset of the identified legal regulations. With this contribution, we set out to provide an early business process model including the specific requirements and impacts for the reverse logistics of EVBs.

The remainder of the paper is structured as follows. In Section 2, we review functions and implications of EVBs and reverse logistics. In Section 3, the design science approach is sketched. In Section 4, selected legal aspects that govern the reverse logistics of EVBs are discussed. In Section 5, the business process model is designed using the Business Process Model and Notation (BPMN). The business process model has been evaluated by checking its compliance with several legal regulations, as depicted in Section 6. Finally, Section 7 concludes the paper by providing a brief outlook on the future development of the reverse logistics of used EVBs.

2 Related Work

EVBs are complex technical components located in EVs, transforming chemical energy into electrical energy to propel the vehicle. An EVB is a battery pack, consisting of several battery modules, each of which consists of several battery cells [ACG+09]. Heating and cooling applications are available to keep the EVB's temperature in an optimal range [YWWS13]. A battery management system (BMS) is an embedded system to monitor and control vital functions of the EVB, including load balancing, temperature control, event logging, etc [LHL+13].

Due to an EVB's cell degradation and an increasing internal resistance, the amount of energy that can be stored in an EVB decreases over time [SUN13]. In order to sustain an EV's range and other driving characteristics, an EVB must be removed from the car as soon as its state of health[1] (SOH) drops below 80% of its initial value [Bu09, CLP+03]. Despite the end of its first life, this amount of energy is sufficient for reusing the EVB in other scenarios that are less demanding [SML+12]. Such a second life is especially feasible when considering the expensiveness of EVBs in terms of their materials and manufacturing process. A SOH of 50% signifies the EVBs' end of life, such that they have to be decommissioned and recycled to retain valuable materials like lithium, nickel, and cobalt [Bu11].

To make EVBs available for reuse or recycling, they have to be collected and transported in a reverse logistics effort. Reverse logistics is an essential part of companies' supply chains and is defined by the Reverse Logistics Executive Council as "[t]he process of planning, implementing and controlling backward flows of raw materials, in process inventory,

[1] EVB's state of health is defined as the ratio of the remaining capacity to the initial capacity [CLH06, YWWS13].

packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal"[Re14, RTL98]. Reverse logistics commonly comprises four main processes, including collection, a combined inspection/selection/sorting process, recovery, and redistribution [dBD03]. Others add that reverse logistics involves a decision process for determining a disposition location [TR02]. Disposition activities such as refabrication, refurbishment, reuse, and recycling are in the scope of reverse logistics [dBD03, RTL98] and apply for the disposition of EVBs, too [Ni10].

However, the generic reverse logistics processes need to be adapted to the specific characteristics of EVBs. For instance, included materials such as lithium [LHL$^+$13] lead to the declaration of EVBs as dangerous goods. In particular, leaking batteries can cause severe damage to the human body and to the natural environment. Therefore, reverse logistics processes need to be designed with close reference to legal regulations that govern the handling and transportation of high-voltage batteries.

A multi-lingual[2] literature search in Google Scholar (number of hits: 52, relevant hits: 0), Springerlink (9, 0), AISEL (0, 0), Scopus (0, 0), and Web of Science (0, 0) resulted in no existing business process models for the reverse logistics of EVBs. Additionally, we have identified research projects dealing with logistics and technical recycling of lithium batteries in general, e.g., LithoRec[3] and LithoRec II[4]. However, the lack of related published scientific literature requests for designing a consolidated business process model in the domain of used EVBs' reverse logistics reflecting relevant legal aspects.

3 Research Method

We set out to design a business process model for the reverse logistics of used EVBs that is compliant with selected legal requirements for transporting high-voltage batteries. A business process model is an IT artifact, which is further defined as language constructs, models, methods, and software implementations [MS95]. Design science research [HMPR04] refers to the design of IT artifacts as a science, building on Simon's [Si77] argument on sciences of the artificial.

In line with the design science research processes [HMPR04, PTRC07] and IT artifacts as prescriptive IS theories [GJ07, Gr06], we conceptualize our research process as follows: First, we conducted a literature review to identify the basic activities that need to be performed in reverse logistics in general. Second, based on these insights and our knowledge about EVBs, we drafted a high-level process model for the reverse logistics of used EVBs. This model was then evaluated and adapted during semi-structured expert interviews with two industry representatives from a recycling consulting company. Third, we identified legal regulations that the business process needs to comply with. The selected legal regulations mainly depend on the experts' recommendations. Fourth, we iteratively redesigned

[2]((“electric vehicle battery” OR “traction battery” OR “evb” OR “traktionsbatterie” OR “antriebsbatterie”) AND (“reverse logistics” OR “reverse flow” OR “rückwärtslogistik”)), conducted on March 11th 2014.

[3]http://www.lithorec.de

[4]http://www.lithorec2.de

and detailed the business process model with consideration of the identified legal regulations and in collaboration with the experts, until saturation of this detailed business process model was reached. Fifth, for emphasizing the validity of the business process model, a matching between business tasks and legal regulations was conducted. Further criteria (e.g., process performance, limitations of handovers) have not been considered at this early point of research.

4 Legal Regulations Influencing the Reverse Logistics of EVBs

Abundant European and country-specific recommendations, regulations, and laws govern reverse logistics processes of EVBs. German and the superordinate European regulations, rules, and recommendations refer to the materials composed in EVBs such as the REACH regulation, the ’Chemikaliengesetz’ (ChemG) or the ’Giftinformationsverordnung bzgl. Chemikalien’ (ChemGiftInfoV), to laboratory protection (e.g. the ’Gefahrenstoffverordnung’ (GefStoffV)), whereas other rules apply for transporting dangerous goods (e.g. ’Accord européen relatif au transport international des marchandises Dangereuses par Route’ (ADR) and ’Gefahrgutverordnung Straße, Eisenbahn und Binnenschifffahrt’ (GGVSEB)), and still other regulations apply to the recycling of batteries (’Batteriegesetz’ (BattG)), cars (e.g. ’Altfahrzeugverordnung’ (AltfahrzeugV)), or goods in general (e.g. ’Abfallverbringungsgesetz’ (AbfVerbrG), Kreislaufwirtschaftsgesetz (KrWG)). Additional rules are released by authorities such as the Federal Institute for Materials Research and Testing (BAM) or company networks such as the German Electrical and Electronic Manufacturers’ Association (ZVEI) and the Association of German Engineers (VDI).

Since we develop a first business process model for the reverse logistics of EVBs, we focus on those sources that allow for providing a comprehensive overview about the redemption, storage, and transportation of EVBs. On the other hand, further aspects with regards to labor protection and details about applied chemical materials and their individual handling are left out here for the sake of simplification.

As an overriding authority, the legislation of the European Union (EU) shapes the national regulations of the EU member states. For reverse logistics of EVBs the EU directive 66/2006/EC is important since it stipulates the duty of EVBs’ redemption of OEMs and defines recycling proportions. EU directive 2008/68/EC concerns the inland transportation of dangerous goods. Another EU related regulation and probably the most important one for transportation issues is the ADR. The ADR is a superior regulation regarding transportation policies of dangerous goods and concerns manifold domain-related aspects such as packing, dispatching, carriage, and receipt of these goods.

From a German perspective, the KrWG contains general regulations about avoidance, reuse, recycling, exploitation, and disposal of waste in Germany (§6 (1) KrWG). Originally, the KrWG was supplemented by a legal decree concerning the disposal of batteries. In 2009 the KrWG was refined and this legal decree was transformed into the BattG. Additionally, the EU directive 66/2006/EC was also implemented into national law by the BattG. With respect to EVBs these regulations mainly focus on the OEMs’ duty of redemption and exploitation (§9 (1) sentence 1 BattG) that also applies for waste management service providers governed by public law (§13 (1) BattG). If exploitation cannot be achieved, an EVB's disposal is mandatory (§14 BattG). In the context of the BattG, EVBs are classified as industrial batteries (§2 (5) BattG).

Four additional national regulations are crucial for the handling, storage, and transportation of EVBs. First, the AltfahrzeugV is a regulation that mainly contains procedural instructions for EVBs, e.g., regarding the immediate removal of EVBs from EVs on receipt (Appendix 3.2.2.1 AltfahrzeugV) and certain instructions for interim storage of EVBs (Appendix 3.1.2.4 AltfahrzeugV). Second, the GGVSEB contains regulations for the transportation of dangerous goods with regard to different stakeholders such as the carrier (§19 (2) GGVSEB), the vehicle driver (§28 GGVSEB) and the consignee (§20 GGVSEB). GGVSEB transposes EU directive 2008/68/EC to national law and, thus, mainly refers to ADR regulations. Third, in accordance with §8 GGVSEB and 1.5.1.1 ADR the Federal Institute for Materials Research and Testing (BAM) is declared as the German national competent authority for assessing the adequate (pre-)processing of dangerous goods.[5] As a consequence for (reverse) logistics of EVBs, the 'Allgemeinverfügung für beschädigte Lithiumbatterien' (AVLIB), released by BAM, regulates the proper handling of damaged EVBs in general. For these batteries the ordinance covers concrete procedural instructions such as the safe packing of damaged EVBs (articles 4 and 5), adequate authority's notification of scheduled transportation (articles 6 and 7) or labeling of the shipped items as "damaged or defective lithium batteries" (article 8). In contrast, the ADR specifies handling and transportation instructions for undamaged EVBs that can be classified according to the UN numbers 3090, 3091, 3480 and 3481. Fourth and finally, the AbfVerbrG deals with regulations concerning national and transnational transportations of waste. For this work, especially the general obligation for labeling transportation vehicles is a crucial regulation written down to §10 AbfVerbrG.

5 A Business Process Model for the Reverse Logistics of EVBs

With respect to more general reverse logistics models [dBD03, TR02], we derive a high-level business process for the reverse logistics of EVBs (Figure 1) to illustrate the complexity of this endeavor.[6]

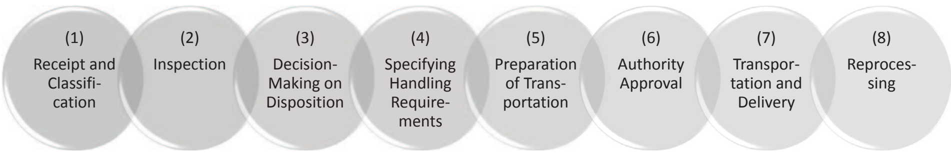

Figure 1: High-level process for the reverse logistics of EVBs

[5] http://www.unece.org/trans/danger/publi/adr/country-info_e.html#Germany

[6] Four crucial processes have been adapted from the theoretical reverse logistics models: 'receipt and classification' (1), 'inspection' (2), 'decision-making on disposition' (3), and 'reprocessing' (8).

Four abstract stakeholders (consignor, approving authority, carrier, and consignee as described by ADR) need to be considered for modeling the reverse logistics process. A consignor is an actor that takes back used goods. A carrier is responsible for preparing the transportation and for shipping the goods to a consignee who further processes the goods. The transport of dangerous goods needs to be permitted by an approving authority in advance.

The high-level process is triggered by the consignor (for instance, a car workshop) following the handover of an EV for replacing an EVB (1). The dismantled EVB has then to be inspected to detect any damages (2). This step is crucial to determine an appropriate disposition destination (3). Subsequently, handling requirements have to be specified (4) that also influence the preparation of the EVB's transportation (5). Depending on an EVB's condition, the approving authority is contacted to permit the transport (6). The transport itself is conducted by a qualified carrier (7). Finally, the consignee accepts the shipped item, such that all necessary reprocessing steps can be applied to the EVB (8).

Since the routing of used EVBs through this process needs to comply with the identified legal regulations and the process needs to be implemented into a software system, a more detailed process model is required. For refining the high-level process, we acquired domain-specific knowledge by industry representatives from a consulting company, who frequently deal with the design and implementation of recycling networks in their day-to-day work. Based on their feedback, the high-level process was detailed into a business process model designed with BPMN (Figure 2).

In the following, the detailed business process is described with reference to the involved stakeholders and the activities. In comparison to the high-level process, the only change regarding the stakeholders is the level of abstraction with respect to the roles of both the consignor and the authority. The consignor needs to be split up into the roles 'regular employee' and 'electrically qualified person'. This is necessary since only specifically trained personnel may operate high-voltage facilities. The authority 'federal institute for materials research and testing (BAM)' is divided into the roles 'risk prevention officer' and 'general authority' as there are operational and administrative tasks conducted by the BAM.

The detailed process resembles the abstract process and is started by the consignor. The first high-level process step 'receipt and classification' is represented by the tasks a regular employee carries out. A regular employee (for instance, a mechanic) of the consignor accepts an electric vehicle provided by a customer. The next step is to identify the containing EVB's type and specification, either by checking the EV's OEM manual or via database lookup in an OEM's knowledge base, or both. This identification is necessary since the further treatment of the EVB depends on its type (UN number). Subsequently, the EV is connected to a computer via an interface (e.g. CAN bus) to read out the EVB's data stored in the BMS. Among others, this data is required for making a sound decision for the optimal disposition of the EVB later on. The job of the regular employee is finished by contacting an electrically qualified person who is able to deal with the EVB on a technical level.

The next three high-level process steps 'inspection', 'decision-making on disposition', and 'specifying handling requirements' are carried out by an electrically qualified person[7] of the consignor or a risk prevention officer of the authority. These three processes are highly complex due to the involvement of several stakeholders and process decisions that have to be made.

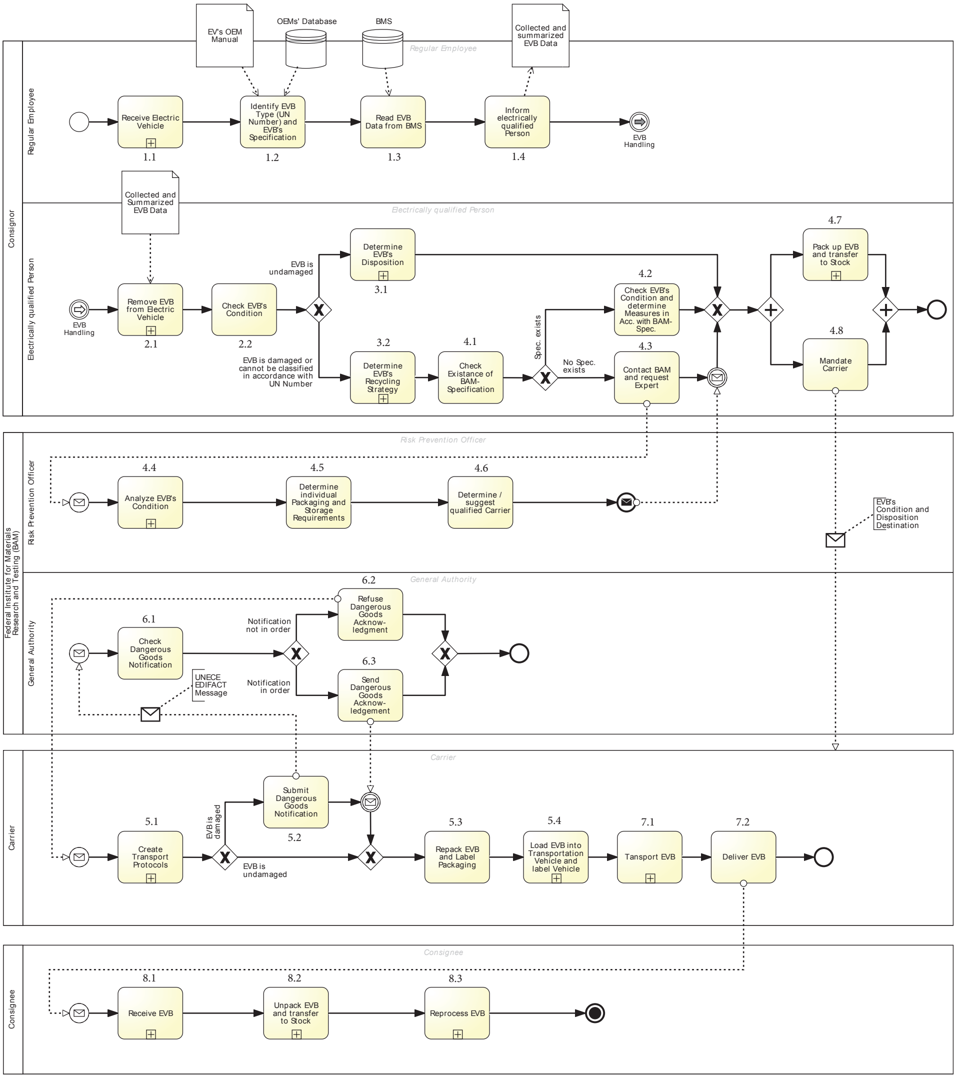

Figure 2: Detailed business process model for the reverse logistics of EVBs

[7]In Germany, a person with a proper qualification level is called 'Elektrofachkraft für Hochvolt-Systeme in Kraftfahrzeugen' as declared by BGI/GUV-I 8686.

The tasks concerning an EVB's removal and condition check are subordinated to the high-level process 'inspection'. An EVB's inspection implies operating with high-voltage systems. Conducting such highly specialized operational tasks requires a sophisticated education of an electrically qualified person. Based on the collected and summarized EVB data the removal of the battery is conducted since each OEM applies an individual design to the EVBs. Before removing the EVB, the qualified worker has to consider security rules, e.g., pulling the service-plug for unlocking the EVB or prevention of turning the EVB back on. Then, after unloosing screw connections the removal of the entire EVB is carried out. Afterwards, the EVB is checked for its general condition that is roughly divided into two states: (1) damaged and (2) undamaged. Checking an EVB's condition is carried out by visual control. The aim is to detect damages such as liquid or gaseous outflows caused by, e.g., leakages. This evidence is highly important for the rest of the reverse logistics process since a damaged battery triggers a special logistics processing of the EVB in comparison to an undamaged battery.[8] Treated insufficiently, a damaged EVB may cause severe and undesired effects such as fire, electric shocks, intoxication, chemical burns, or other serious harms to humans and the environment. Hence, it is necessary to apply extended reverse logistics services like sealing, boxing, etc. to damaged EVBs.

Considering the high-level process 'decision-making on disposition', determining an EVB's disposition is a binary decision. Based on the EVB's condition figured out before, the battery either has to be recycled or can be forwarded to a different disposition such as reuse, refabrication, and refurbishment. Furthermore, this decision is important for the high-level process 'specifying handling requirements' that is next.

If the EVB is found to be undamaged, there are no specific handling requirements other than described by common law dealing with the transportation of dangerous goods. Otherwise, if the battery is found to be damaged, recycling must take place. For that to happen, an adequate recycling strategy is selected. Then, a lookup for a BAM specification (special approval for the transportation of damaged EVBs) of the battery type is conducted. If such a specification is available, the containing procedural instructions apply, e.g., for storing, packing, and labeling the battery. If there is no BAM specification available, a risk prevention officer of the BAM has to be contacted for analyzing the damaged EVB's condition in detail, determining certain procedural instructions which should apply and suggesting a qualified carrier. Finally, operational processes of packing up the EVB and transferring it to the interim storage take place. Additionally, the suggested carrier is mandated who is responsible for the 'preparation of transportation'.

The 'preparation of transportation' is conducted by the suggested carrier. After creating the transport protocols, the EVB's condition again is the basic criterion for the carrier to proceed. If the battery is damaged, the high-level process 'authority approval' comes into play and the general authority has to be informed about the upcoming transportation by sending a (standardized) dangerous goods notification.[9] This federal instance then performs a contentual check of this notification and either accepts or declines it. If declined, the carrier potentially has to overwork the suggested packaging and labeling and needs to edit the document accordingly. Otherwise, the carrier is allowed to proceed with the

[8] This special processing also applies for EVBs that cannot be classified in accordance with the UN numbers.
[9] http://www.unece.org/trade/untdid/d01a/trmd/iftdgn_c.htm

preparation of transportation as declared in the transport protocols. In general, if the EVB is in an undamaged condition and has been classified according to an UN number, there is no authority approval needed for the transportation. If circumstances so require, the carrier repacks the battery for transportation and applies labeling to the completed packaging. The preparation is finished by loading and labeling the transportation vehicle.

Finally, the high-level processes 'transportation and delivery' and 'reprocessing' are conducted. A qualified driver of the carrier conducts the EVB's transportation from start to target destination under consideration of all operational requirements stipulated by traffic law. After EVB's delivery, the consignee concludes the entire reverse logistics process by unpacking, storing, and reprocessing the EVB.

6 Evaluation of Business Process Model

In the previous sections we presented relevant legal regulations and a detailed business process model for transportation of EVBs. In the following we conduct an evaluation based on a particularized mapping of aforementioned legal regulations to the detailed business process model. For that to happen, each process task is provided with a unique identifier (see Figure 2). The mapping is realized by a table that shows all process task identifiers on the left and matching legal regulations and their impact on the right (Table 1).

ID	Legal regulation	Impact
1.1	§5 (1) BattG; §6 (1) KrWG	Duty of OEM for redemption of EVBs
1.2	ADR 2013 2.2.9.1.7	Requirement for classifying EVBs according to an UN number allowing a handling according to ADR
	UNECE Manual of Tests and Criteria - Rev.5 subsection 38.3	Every cell and battery has to comply with a type, for which the testing requirements as specified in this definition have to be fulfilled. Otherwise, a transport is only possible on special permit.
	ADR 2013 3.3 SP 188	If cells and batteries meet requirements of SP 188, they are not affected by other rules of ADR.
1.3	e.g. D/BAM/GGVSEB (ADR)/2.2-256/12-rev.1, Annex	Testing of cells requires reading out data from battery management system for getting information about defective cells.
1.4	See 2.1	
2.1	BGI/GUV-I 8686 1. Anwendungsbereich	Necessity for proper qualification to deal with high-voltage facilities
	Appendix 3.2.2.1 AltfahrzeugV	EVBs have to be removed immediately on receipt.

continued ...

ID	Legal regulation	Impact
2.2	ADR 2013 1.5.1 → Multilateral Agreement M259 (2.2) ADR 2013 3.3 SP 661 AVLIB 3.1	Requirement for differentiating between damaged and undamaged EVBs In case of a damaged or defect battery or cell, the previous (erroneous) application has to be taken into account.
3.1	-	
3.2	ADR 2013 3.3 SP 661; Exceptions to SP 661 are possible under certain requirements ADR 2013 3.3 SP 636	Transportation of damaged EVBs requires approval of competent authority, including possible restrictions of packaging methods and transportation routes (tunnel restrictions).
4.1	ADR 2013 3.3 SP 661	Transportation of damaged EVBs requires approval of competent authority.
4.2	e.g. D/BAM/GGVSEB (ADR)/2.2-256/12-rev.1, Annex	BAM exception specifications contain detailed requirements concerning to be performed tests, packaging, driver, vehicles, labeling, etc.
4.3	See 4.1	
4.4	See 4.7	EVB's detailed condition determines packaging requirements (reacted vs. not reacted cells and batteries).
4.5	ADR 2013 3.3 SP 661	Necessity for competent authority to determine packaging, storage and transportation requirements. During granting, any recommendations of UNECE have to be taken into account.
4.6	-	
4.7	All: Appendix 3.1.2.4 AltfahrzeugV Undamaged: ADR 2013 1.4.1 (1.4.1.1), 1.4.3.2, 4.1.1, 4.1.3, 4.1.4.1 Damaged (not reacted): Multilateral Agreement M259, AVLIB 4 and 5 Damaged (reacted): ADR 2013 4.1.4.3 and M259, AVLIB 4 and 5	Depending on condition of EVB, specific packing and storage requirements apply (e.g. acid-proof packaging, storage location).
4.8	-	
5.1	ADR 2013 5.4.1 Damaged: AVLIB 7.1	Transport of EVBs has to be accompanied with structurally predefined transport protocols. If AVLIB is applied for transporting a damaged EVB, a copy of AVLIB has to be added to the transport documents.

continued ...

ID	Legal regulation	Impact
5.2	ADR 2013 3.3 SP 661 AVLIB 6.1.1	An acknowledgment is required for the transport of damaged EVBs.
5.3	All: ADR 2013 5.2.1, 5.3.1, §10 Damaged: AVLIB 8.1	Depending on battery state, the transport of EVBs requires special labeling of packaging and vehicles.
5.4	ADR 2013 1.4.3.1, 1.4.2.1 §10 AbfVerbrG	Duties for loader and consignor Requirements for labeling of the vehicle
6.1	AVLIB 6.1.3	Requirement for a proper dangerous goods notification and call for acknowledgment
6.2	AVLIB 6.1.2 and 6.1.3	Non-compliance of transport intent/message
6.3	AVLIB 6.1.2 and 6.1.3	Compliance of transport intent/message
7.1	§19 (2) GGVSEB; §28 GGVSEB Damaged: ADR 2013 3.3 SP 661	Existence of special duties of carrier and vehicle driver concerning road safety In case of damaged EVBs, a copy of the approval or a reference to the competent authority has to be included.
7.2	Damaged: AVLIB 6.1.5	If any incident occurred during transportation, reporting to BAM is required.
8.1	ADR 1.4.2.3, 1.4.3.7; §20 GGVSEB	Duties of consignee and unloader
8.2	Appendix 3.1.2.4 AltfahrzeugV	Requirements for storing EVBs
8.3	§6 (1) KrWG; §14 BattG	Duty for exploitation of waste

Table 1: Mapping of legal regulations to process tasks

7 Limitations and Outlook

The theoretical and managerial contribution offered by this paper is a business process model for the reverse logistics of EVBs that complies with some of the most important legal regulations in Germany. The work, therefore, extends previous thinking on this issue that has started to develop initial insights, but refrained from designing a detailed business process model with reference to selected legal regulations. Thus, our results are envisioned to inform subsequent research related to EVBs and electric mobility in general.

In the spirit of the design of IT artifacts as a search process [HMPR04], the business process model is envisioned to be a first step towards realizing compliant business processes and implementing them into software tools. Since the reverse logistics of EVBs is subject to abundant laws and regulations, the process must be further developed to comply with more regulations than could be reviewed here, capitalizing on the expert knowledge on lawyers and professionals for handling dangerous goods. Before putting the process into action, we suggest to perform a process of certification in addition, supervised by an independent certification agency.

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