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Electric Actuation of Transport Vehicles: Overview of Technical Characteristics and Propulsion Solutions through a Systematic Patent Analysis

Davide Consolati [1,2], Paolo Marmaglio [1,2], Lorenzo Canziani [1], Monica Tiboni [1] and Cinzia Amici [1,*]

[1] Department of Mechanical and Industrial Engineering, University of Brescia, Via Branze 38, 25123 Brescia, BS, Italy; davide.consolati@unibs.it (D.C.); paolo.marmaglio@unibs.it (P.M.); l.canziani@studenti.unibs.it (L.C.); monica.tiboni@unibs.it (M.T.)

[2] Antares Vision S.p.A., Via del Ferro 16, 25039 Travagliato, BS, Italy

* Correspondence: cinzia.amici@unibs.it

Abstract: Electric transport vehicles offer sustainable transportation solutions with benefits, such as reduced emissions, noise, and operating costs. This paper draws an overview of the available technical solutions to actuate transport vehicles with electric drives, as depicted by patent literature. A dataset of 1784 patents was created; the documents were selected through a systematic approach, and the patents were then classified according to a number of user-defined categories. The dataset was analyzed by applying two different methods: (i) a quantitative analysis (literature overview), enabling glance evaluations about the defined categories, and (ii) a qualitative analysis (detailed analysis), which focuses on the detection of interesting design features or innovative solutions. The results of this work not only provide an alternative and complementary overview to the analysis of solutions that may emerge from a scientific literature review, but can also offer support in strategic planning to companies wishing to protect their innovations and remain competitive in the evolving market of transport vehicles.

Keywords: electric carts; electric trolleys; manual and autonomous vehicles; patent analysis; transportation

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1. Introduction

In recent decades, the interest in sustainable mobility has led the industry to develop innovative solutions in the transport sector [1,2]. In this context, electric transport devices have emerged as a promising alternative to conventional vehicles powered by fossil fuels. Due to their electric power supply, electric transport systems offer significant advantages in terms of reducing greenhouse gas emissions, and operating costs [3]. Electric transport devices can also help reduce noise pollution in urban and suburban regions [4]. Electric actuation of transport vehicles is an important topic in the field of transportation electrification. While electric and hybrid vehicles have gained attention, there are other aspects of transportation electrification that are often overlooked. In particular, in this work, the term 'electric vehicles' is used in a broad sense: it is not necessarily intended as cars but rather encompasses all electrically-driven systems such as trolleys, carts, or machines in general. These vehicles can move within a space to transport goods and/or people, powered by electric actuation. These systems could present different levels of autonomy in the motion, passing from passively pushed trolleys, to driven golf carts, to autonomous drones, like unmanned aerial vehicles. The scientific literature presents different works that investigate specific details of these innovative solutions or their expected evolution trends [5], often referring to specific application fields and regulation frameworks [6].

On the other hand, no investigations regarding the innovative solutions depicted in the patent literature seem to be currently available. Nevertheless, as the demand for

electric transport devices has increased, the industry is facing heightening competition and a growing need to protect its innovations also in this specific field. In this context, patents play a crucial role: according to the definition of the World Intellectual Property Organization (WIPO), they represent the exclusive right to prevent or stop others from commercially exploiting the patented invention [7], so they enable companies to protect the intellectual property rights of their inventions and ensure a competitive advantage in the marketplace.

The objective of this paper is to examine and analyze patent literature in the electric trolley and cart industry since 2000. A custom classification strategy has been designed and applied to evaluate the dataset of identified patents, with the goal of capturing the most significant characteristics of these technical innovations.

This kind of analysis can offer significant outcomes for both the scientific community and companies, although these players generally present different and integrative needs [7]. For instance, a patent analysis on this topic may offer support to the scientific community in:

- Identifying technological trends: Researchers benefit by gaining insight into prevailing technological trends in electric actuation across a diverse spectrum of vehicles and machinery. This knowledge allows for a nuanced understanding of the broader landscape of electric propulsion systems;
- Detecting innovation opportunities: Through the examination of patents, researchers can pinpoint areas where innovation occurs or is needed. This insight opens up avenues for further research and development, allowing researchers to propose novel solutions and contribute to the progression of electric propulsion technologies;
- Capturing cross-disciplinary insights: A comprehensive analysis covering electric propulsion in both transportation and industrial applications facilitates cross-disciplinary collaboration;
- Broadening the basis for academic research: The analysis provides a solid foundation for academic research by offering a systematic and data-driven overview of the technical characteristics and propulsion solutions in electrically powered vehicles and machinery.

On the contrary, companies may exploit this kind of study for different purposes, such as to develop:

- Market intelligence: Companies can gain valuable market intelligence by understanding the current state of electric propulsion technologies in diverse applications. This knowledge helps companies stay informed about competitors' innovations and market demands, facilitating strategic decision-making.
- Strategic planning; The analysis aids companies in developing strategic plans for future product development and investments in research and innovation. By aligning R&D efforts with identified technological trends, companies can position themselves for growth;
- Patent portfolio management: Companies can use patent analysis to assess and manage their own patent portfolios. It helps identify areas where companies may need to strengthen their intellectual property and areas where they can leverage existing patents for partnerships or licensing agreements;
- Collaboration and partnerships: The analysis fosters collaboration between companies, encouraging partnerships based on complementary strengths and shared goals in electric actuation technologies. Collaborative ventures can accelerate innovation and address common challenges;
- Regulatory compliance and standards: Understanding the technical landscape helps companies anticipate and adapt to evolving regulatory standards in electric transportation and machinery. This ensures that products align with industry regulations, positioning companies as leaders in compliance.

In this sense, through the patent analysis of electric actuation in transport vehicles, this work aims to offer a tool that supports both researchers and companies, integrating the knowledge generally available through scientific literature reviews. This approach can play a pivotal role in advancing knowledge, fostering collaboration, and guiding strategic decisions for both researchers and companies in a dynamic and evolving landscape.

The paper is organized with a schematic rationale: in the following section, applied materials and methods are introduced and briefly explained, then the quantitative analysis is described, in the form of a patent literature overview. Subsequently, the qualitative analysis is presented, i.e., a detailed analysis of the investigated patents, to highlight the most interesting and peculiar characteristics of the proposed solutions. Finally, the conclusions synthesize main findings of the work, limitations and possible future developments.

2. Materials and Methods

In the following, the procedure applied for the data selection, as well as the data processing adopted for the systematic analysis of the identified documents, are presented via a schematic approach.

2.1. Data Selection

The patent analysis was performed by querying the Espacenet database [8] through a rigorous selection process. In order to identify the documents related to electric vehicles, specifically electric carts and trolleys, a search string was designed to ideally detect documents that feature the fundamental words 'electric' and 'carts' or 'trolleys' in their titles.

The two search strings designed to combine possible variations of the desired keywords were, therefore,

(i) "(TITLE (electric AND cart))";
(ii) "(TITLE ((electric AND trolley)NOT for))".

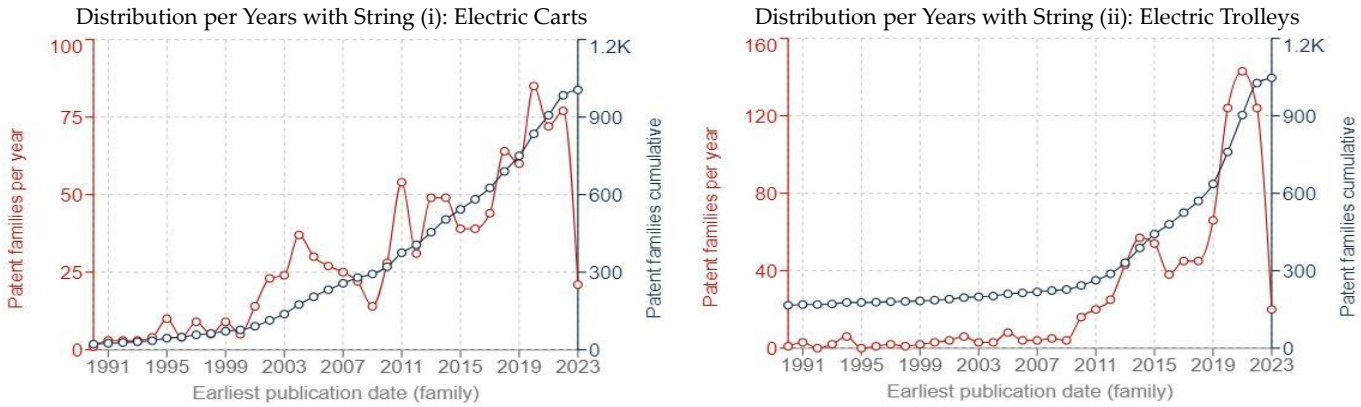
The following inclusion criteria were applied to filter the results: (a) "English language", (b) documents ranked in descending chronological order according to the priority date. The query, last updated on 26 June 2023, provided:

- 1005 patents for string (i);
- 1046 patents for string (ii).

Since data revealed that most of the patents occurred in the last decades, and given the purpose of providing the reader with an up-to-date review, the research string was further refined. Specifically, two exclusion criteria were added: (c) "Earliest Priority Date" had to be from 2000 to 2023, and (d) duplicate instances of the already included patents were excluded. The emerging products were then thoroughly double-checked for coherence with inclusion and exclusion criteria. All the identified patents proved to meet the required requirements and specifications, and were chosen to be part of the final dataset. This final dataset is, therefore, composed of:

- 920 documents for string (i);
- 864 patents for string (ii).

Figure 1 depicts the distribution of the patent families identified with both the search strings by priority date. The final dataset of 1784 patents represents a diverse set of products, covering a wide range of features, performances, and specifications. This diversity allows different aspects of the products to be examined and compared, thus enabling a comprehensive and detailed view of the entire landscape.



(**a**) (**b**)

Figure 1. Distribution of patent families per year and in cumulative format, in red and blue line with dots, respectively [8]: from the left, (**a**) patent families identified with string (i) for electric carts, and (**b**) with string (ii) for electric trolleys.

2.2. Data Processing

2.2.1. Data Elaboration

After identifying the search string, data were extracted and organized for the subsequent phases of data elaboration. During this step, special attention was paid to the accuracy and integrity of the extracted data. This careful formatting allowed for a clear and orderly display of the data in the final table. The following data were extracted:

- *Inventors*: The person or group of people who created an original and innovative invention.
- *Applicants*: Individuals or legal entities that file patent applications with the relevant patent office.
- *Publication number*: The unique numeric code that identifies a published patent, and the number used to refer to that specific patent within the patent system.
- *Earliest priority*: The initial filing date of a patent application. In short, it represents the date from which priority issues and prior public knowledge of an invention are evaluated.
- *IPC*: The International Patent Classification (IPC) is a classification system used to organize and categorize patents based on their technical content; the code assigned to each patent was collected in this context.
- *Publication date*: Date of publication of the patent in question.

A new category was then added that was considered relevant: the "Device Description". This new category is based on specific characteristics of the device, such as its function, design, or other distinguishing features. The goal is to enrich the existing description to provide more in-depth and accurate information about the device in question. Finally, the table containing all the extracted data was saved as an Excel file. This file format is widely used and can be easily opened and manipulated with software such as Microsoft Excel or other similar applications. The Excel file allowed us to store and analyze the data more flexibly and allows for further manipulation and analysis according to specific needs. The required information was extracted by primarily analyzing document titles and abstracts, and evaluating drawings and claims of the patents where needed.

2.2.2. Category Classification

Patent classification plays a key role in the world of intellectual property. It consists of organizing and categorizing patents according to their characteristics to simplify the search and access technical information contained in these documents. Patent classification makes it easier to find related patents and to recognize trends and technological developments in a particular field. As part of the patent classification activity, a categorization system

has been developed that includes macro-categories and subcategories. This system aims to provide a clear and consistent organizational structure for understanding and navigating the wide range of patents processed. The macro-categories were chosen to have an idea regarding the purpose and use of a given patent. These macro-categories were created to facilitate an overview of the different areas of research and development and to help users narrow their search. Within each macro-category, several subcategories have been defined to represent specific subsets of applications. These subcategories allow for a more detailed and specific breakdown of patents within each macro-category, allowing users to focus their search on more specific areas of interest.

In more detail, the development of the patent taxonomy for this study involved a meticulous and iterative process aimed at capturing, at best, the main characteristics and peculiarities of the selected patents. Initially, hypothetical categories were established based on their perceived significance in the world of electric carts and trolleys. As the patent examination progressed, the dynamic review of patents led to the evolution of the initial set of categories, merging or incorporating additional relevant classes and subcategories, while concurrently eliminating those deemed less pertinent. This iterative refinement process was essential to ensure the relevance of the innovations described in the patents, and allowed capturing the evolving landscape of technological advancements in the field. In the following, the final set of categories is presented.

Control System

The category of control systems encompasses and focuses on the application of technologies, which enable the precise monitoring and regulation of a system's operation to achieve the desired results. Within the broader category of control systems, four different sub-categories have been selected. These sub-categories provide a more detailed breakdown and focus on specific aspects of control systems:

- *Stationary*: A trolley with locking devices or without wheels that do not allow its movement; the trolley will, therefore, only be able to work in a fixed position;
- *Manual*: A transport device designed to be pushed or pulled manually by users without the aid of motors or power systems;
- *Semi-automatic*: A device designed to facilitate the transport of heavy or bulky loads. Typically, an assisted trolley has an electric motor or power system that provides the necessary thrust or traction to move the trolley;
- *Automatic*: A device that moves autonomously without the need for human intervention. This cart is designed to perform specific transportation or handling tasks within a predetermined environment, such as a warehouse, production area, or logistics center.

Type of Transport

The category "Type of Transportation" is a classification used to identify specific patents and innovations in the field of purpose of the trolley in relation to transport. This category focuses on the modes of transportation used to move goods or people from one place to another. Two sub-categories are identified:

- *Transport of people*: Vehicles designed to move passengers from one place to another conveniently and efficiently. These trolleys are widely used in a variety of settings, such as airports, golf courses, hospitals, and wherever the mobility of people over short distances is required. People-transport carts are designed with several important considerations in mind. They must be able to accommodate an adequate number of passengers. Depending on the specific needs, they can vary in size and configuration, allowing the transport of different amounts of people.
- *Transport of goods and objects*: Devices designed to facilitate the movement of goods, materials, or objects from one point to another efficiently and safely. The trolley can be used in various industries, such as logistics, warehousing, manufacturing, and retail, to simplify the transportation and handling of goods. A freight cart is designed to support the load of goods stably and safely. It may be equipped with a platform,

side rails, or other retention mechanisms to prevent goods from shifting or falling during transport.

Field of Use

The "Field of Use" category is a classification that identifies the different areas in which a cart can be used for specific purposes. This category is intended to provide additional classification for patents and innovations involving carts, allowing for greater specificity in identifying the applications and functions of carts. Within this category, several subcategories can be found that represent the different sectors or areas in which the trolleys are used:

- *General use*: General-purpose carts have features that make them suitable for multiple purposes. They usually have a platform or support structure on which to place items to be transported. This platform can be adjustable in height or size to accommodate different loading needs.
- *Sports use*: These vehicles are used in sports or recreational settings. Sports carts are designed to meet specific transportation or handling needs within sports or entertainment activities. They can be used to transport sports equipment, materials, or even participants in certain disciplines.
- *Agricultural and environmental use*: These carts are adapted to meet the handling needs of materials, equipment, or products in agricultural and environmental settings, facilitating tillage operations, crop management, fertilizer, or pesticide distribution, or even cleaning and maintenance of green areas and public spaces.
- *Food use*: These carts are designed for handling, transporting, or storing food products, ensuring the safety and hygiene required in the food environment.
- *Children's use*: These carts are devices are designed specifically for transporting and caring for children, and in some cases are also designed as children's toys,
- *Airport use*: These trolleys are designed to facilitate the transportation of luggage within airports. These carts are used to enable passengers to move their luggage conveniently and efficiently during check-in, baggage claim, and other transit times within the airport,
- *Medical and rehabilitation use*: These carts refer to the use of these devices in the healthcare setting to transport medical equipment and supplies, and to facilitate patient mobility during rehabilitation.

Number and Type of Wheels

Carts are transportation devices that can be equipped with different numbers of wheels or, alternatively, tracks. This variety of configurations allows trolleys to adapt to the specific needs of use in different contexts. A *single-wheel* cart is distinguished by its agility and maneuverability. Because of its single wheel, it can tackle rough terrain or tight spaces with relative ease. *Two-wheel* carts offer greater stability than unicycles. Due to the presence of two wheels, one in front of the other, these carts provide better balance and ease of riding. They are suitable for transporting people or light goods on paved roads or paths. *Three-wheel* carts, known as tricycles, are designed to provide even greater stability than two-wheel carts. The presence of an additional wheel at the rear or front of the cart improves weight distribution and balance. *Four-wheel* carts are the most common configuration and offer optimal stability. With two pairs of wheels, one in the front and one in the rear, these carts distribute weight evenly, providing greater safety and ease of movement. Finally, *tracked* carts are equipped with a track system instead of wheels. This type of cart offers better traction and grip on the ground, making it suitable for dealing with difficult conditions, such as mud, snow, or rough terrain. Tracked carts are often used in off-road settings, such as in construction or agriculture activities.

Safety and Decreased Workload

The safety and workload reduction category focuses on patents that aim to provide a safe working environment and reduce the physical burden of workload. Two subcategories are distinguished here: in the *safety* subcategory, solutions are developed to prevent accidents and injuries in the workplace. This may include personal protective equipment, alarm systems, safety procedures, and ergonomic equipment designed to reduce risks and provide a safer work environment. In the subcategory of *workload reduction*, solutions are developed that aim to reduce the physical effort required to perform certain work activities. This may include automating processes, using advanced technologies for lifting and carrying heavy loads, optimizing workflows, and introducing ergonomic tools and equipment to reduce fatigue and improve work efficiency.

Interface with the User

This category explains the different methods used concerning the interface with the user. Three different types of interfaces are identified in this case:

- *Handlebar*: A control device that uses a handlebar as the primary means of interaction. A handlebar is generally a lever or bar that can be rotated, tilted, or pushed to control and steer a device.
- *Steering wheel*: A system that allows users to interact with a device or machine using a steering wheel as the primary means of control.
- *Handlebar with an attached support platform for feet*: A system that integrates support for the user's whole body.

Country of Validity

This macro-category describes the country of validity of a patent. It refers to the jurisdiction in which a patent is valid and has legal protection. The choice of the country of validity of a patent generally depends on the business strategies of the applicant. A patent is generally filed in one or more countries where the patentee intends to commercialize or protect their invention. However, the process of obtaining and maintaining the validity of a patent in several countries can require significant cost and effort, and patent laws may vary from country to country, including patentability requirements, application procedures, and durations of protection [7]. Therefore, it is important to carefully consider the choice of country of validity to maximize the benefits obtained from the patent and ensure the effective protection of the invention.

2.2.3. Data Analysis

The dataset of collected patents was analyzed using two different methods: (i) a quantitative analysis, enabling glance evaluations of the defined categories, and (ii) a qualitative analysis, which focuses on the detection of interesting design features or innovative solutions.

Quantitative Analysis: Patents Overview

For the quantitative analysis, data were evaluated with percentage graphs: on the one hand, the number of patents in each macro-category and subcategory was evaluated with respect to the total amount of analyzed patents, and on the other hand, the relative percentage value of each subcategory within the relative macro-category was computed. The use of percentage graphs provides an effective way to analyze and present data, allowing us to effectively highlight the contribution of each item relative to the total and within individual categories. By expressing results as percentages of the database total, we can easily understand the proportional representation of each item or category in the entire database. In addition, expressing the results as partial percentages within subcategories allows for more detailed analysis. By dividing the data into subcategories, we can evaluate the performances of individual subcategories within the macro-category, and identify specific trends.

Qualitative Analysis: Detailed Analysis

Patent research can offer a wide range of information beyond the core of the invention. Given its intrinsic variability, the information was organized into three main categories:

- Out-of-Topics;
- Smart Devices;
- Design Cues.

The category "Out-of-Topics" collects patents presenting elements that might be considered outside of the focus stated for the categories under consideration. Nevertheless, those patents should be considered during the qualitative analysis: "Out-of-Topics" can, in fact, be a treasure trove of inspiration for future design and research, even when not closely related to the research in question, insofar as they are part of products and innovations outside the research topic.

Moreover, several possible categories of analysis or thematic focus emerged during the analysis, allowing for detailed or qualitative analysis. Among these, special attention was given to intelligent devices, meant as those devices capable of integrating sensors or solutions that render them smart. These systems have become increasingly present in modern patents, and the referring documents have been collected within the "Smart Devices" category. Qualitative analysis can explore in detail how these devices are implemented and what smart functionality they offer. Sensors, artificial intelligence, and machine learning are just some of the elements that can make a device smart. This analysis provides insight into how the invention integrates into the technology ecosystem and how it can improve user interaction, efficiency, or process security.

Finally, a third category has been considered, namely "Design Cues". This class collects those devices that, although not smart, could provide suggestions for new or optimized concepts. "Design Cues" from the qualitative analysis of a patent search can, therefore, be a valuable source of inspiration for developing new products or improving existing ones. During patent examination, it is possible to identify interesting design features, creative solutions, or innovative technological approaches that can be applied in various contexts.

Both "out of topic" and "smart devices" were not categorized. The only type of categorization that was conducted on "smart devices" regarded the country of patent validity. No other categorization was made as it was not possible to uniquely choose categories for each individual smart device.

3. Patents Overview

A quantitative analysis was carried out for those patents for which data were available. Data were organized into three groups of characteristics, summarized in Figure 2: the first set of categories mainly focused on the context of the use of the device; the second set of characteristics especially dealt with technical details and design solutions, and finally, the third family collected the countries of validity of the analyzed patents. Figures 3, 5 and 7 synthesize the numerical distribution of the patents among these three macro-groups.

3.1. Field of Use

The achieved results reveal that the predominant subcategories in the macro-category "Field of Use" of electric carts, both in the total database and in the partial category, are general use, sports use, agricultural use, and medical/rehabilitation use (see Figure 3). These categories represent the main application areas in which electric carts find use. In the general use area, electric carts are used for a wide range of everyday purposes and activities, and this is reflected in a wide variety of device shapes and dimensions, as Figure 4 depicts. For example, they could be used to transport goods within warehouses [9], in logistics centers [10], or for material handling operations in various industries [11]. In addition, general-purpose electric carts can also be used in the public sector, such as in park management or city operations. In the area of sports use, electric carts find application in various recreational and sports activities. For example, they can be used to transport sports equipment to golf courses, facilitating the movement of players along the course [12].

In addition, they can be used in sports facilities to ease the movement of equipment and ensure an organized and functional environment [13]. As for agricultural use, electric carts are adopted in various agricultural settings to carry out a variety of activities. For example, they can be used to transport farm implements, pickers, and loads of agricultural products within farms [14]. Electric carts can improve the efficiency of agricultural operations by enabling smooth transportation and reducing the physical fatigue of operators. In the medical/rehabilitation field, electric carts are used in hospitals, healthcare facilities, and rehabilitation centers to transport patients [15], medical equipment, and supplies [16].

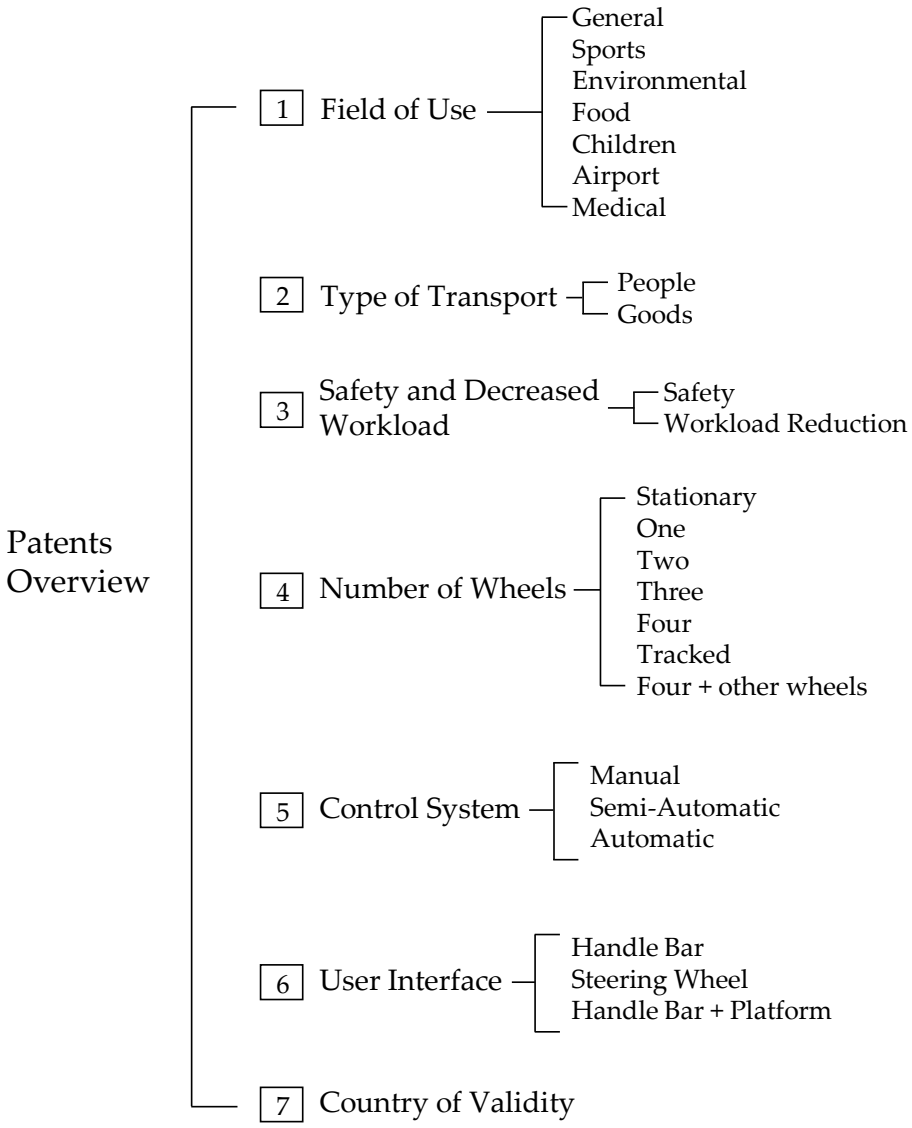


Figure 2. Patent classification taxonomy: categories and sub-categories used for the classification of the analyzed patents.

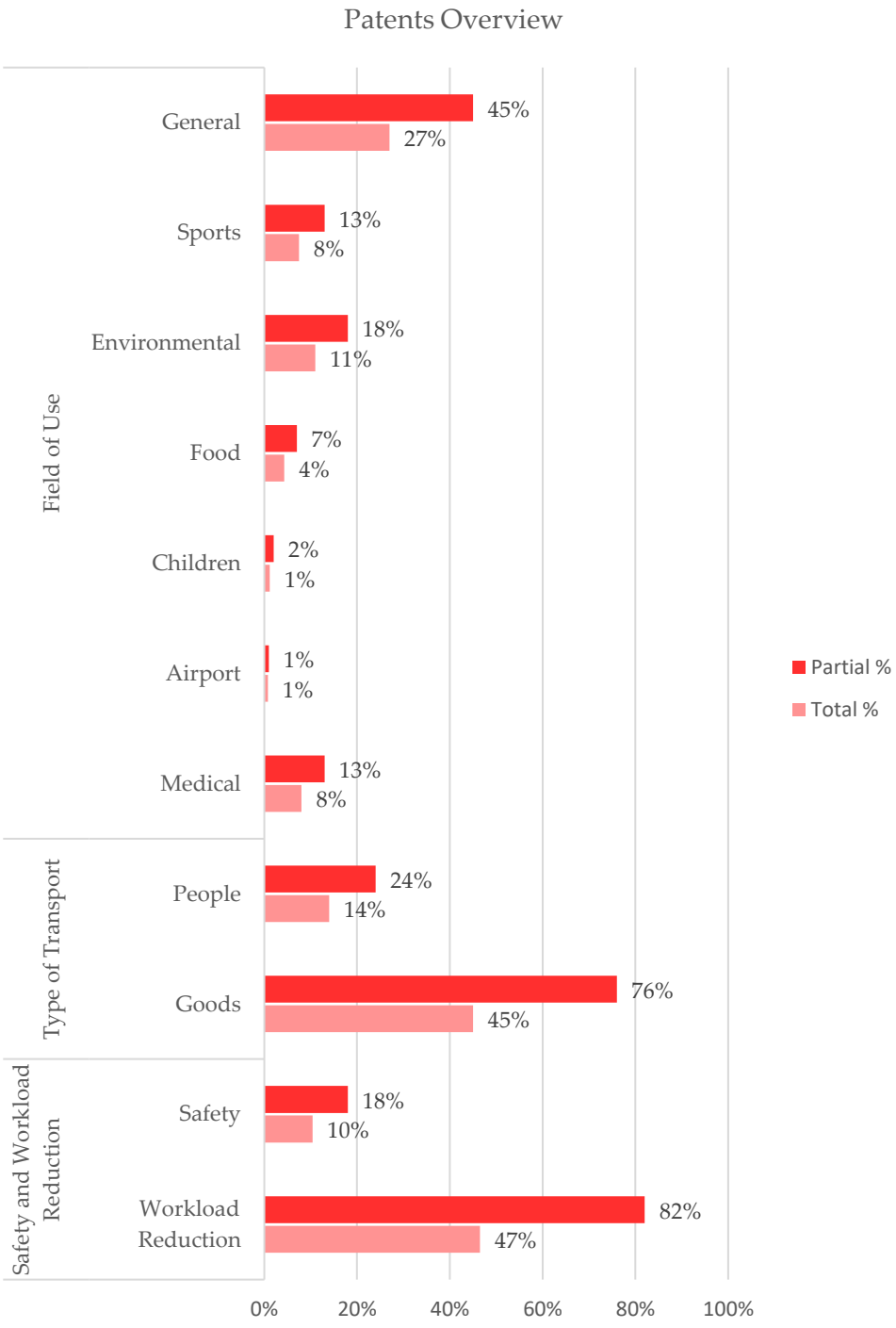


Figure 3. Distribution of patents by macro-categories and subcategories for the group referring to the context of use. The darker color represents the relative percentage value of the subcategory within the relative macro-category, while the lighter color represents the percentage value of the subcategory with respect to the total amount of analyzed patents.

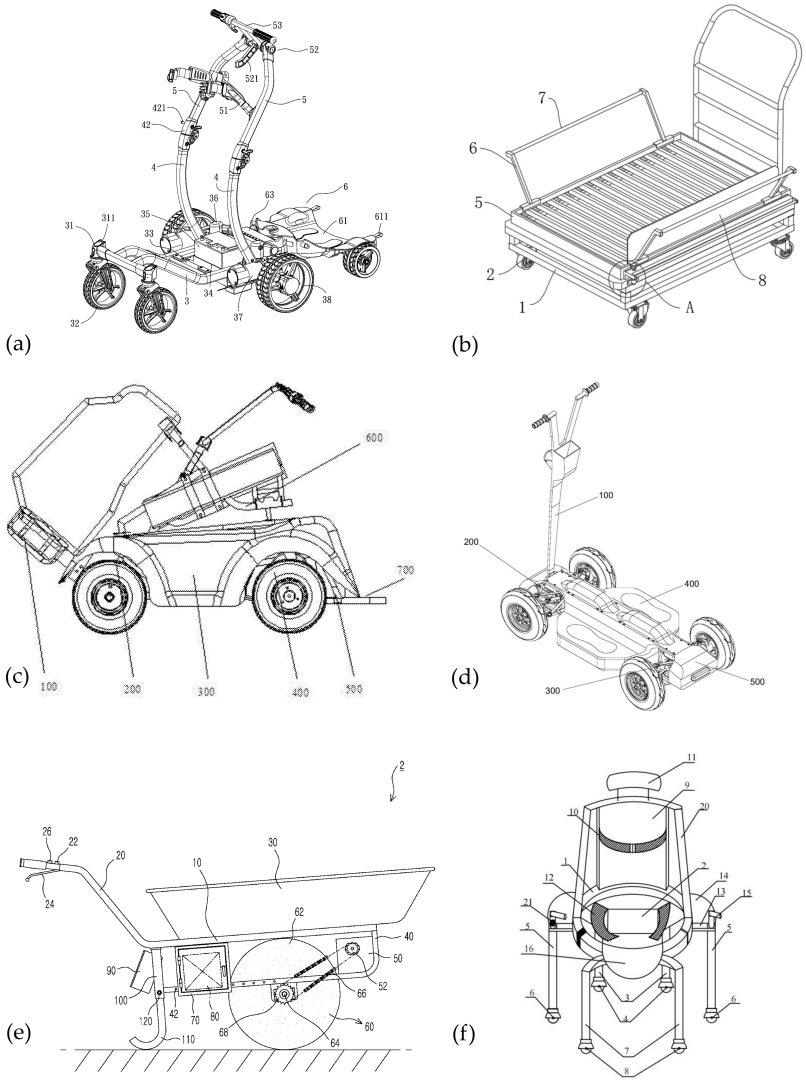


Figure 4. Examples of vehicles for different fields of use: (**a**) an electric golf cart for sports [17], (**b**) an electric trolley for logistic transfers [10], (**c**) an electric standing driving type golf trolley [12], (**d**) an electric golf cart for the transport of humans [13], (**e**) an electric cart with one wheel for agriculture, to shift the center of gravity [18], and (**f**) in the medical field, electric rehabilitation walking cart [15].

3.2. Type of Transport

From the results, it significantly emerges that the preponderant category of "Type of Transport", both in the total database and in the partial category, is the subcategory goods and objects [19]. This indicates that the main focus and interest is on the transportation of tangible goods rather than the transportation of people. The 45% indicating the subcategory of transportation of goods and objects in the total database reflects the importance of this sector. This result could be attributed to the growing demand for efficient and reliable transportation solutions for commercial and industrial activities, where the transportation of goods and objects is essential to secure the supply chain and meet customer needs. In addition, the high percentage (76%) of the transportation of goods and objects within the partial category indicates that, even among the more specific types of transportation considered in the research, the transportation of tangible goods is predominant. This suggests that there is a greater emphasis on developing innovative solutions to improve the efficiency, safety, and sustainability of goods and object transport. The predominance of freight or object transportation in the total database and partial category reflects the economic and logistical significance of this sector. As goods transportation is a key element

in business procurement and product distribution, the adoption of advanced technologies and effective solutions in this field can bring significant benefits in terms of delivery time, cost reduction, and customer satisfaction [20]. Regarding this category, the wide variety of electric carts for transporting materials in industrial, agricultural, and even medical fields, such as carts for transporting medicines, can be noted [16]. Although the percentages of the subcategory of transporting people are significantly lower—14% of the total and 24% of the partial—they are important in daily life. In the medical/rehabilitation field, wheelchairs for rehabilitation or stretchers for hospitals were analyzed [21], strollers were processed for children and carts for transporting people to golf courses in the sports field [22].

3.3. Safety and Decreased Workload

Considering the category of "Safety and Decreased Workload" of electric carts, as Figure 3 depicts, the preponderant subcategory in both the total (47%) and partial (82%) databases is "Decreased Workload". This indicates a strong interest in the development of solutions to reduce the physical effort required from the operator while using electric trolleys. The "Decreased Workload" subcategory encompasses a range of features and technologies implemented in electric transport vehicles to reduce the operator's physical footprint and facilitate handling and transport operations. This may include the use of automatic lifting and lowering systems, driver assistance devices, advanced control technologies, and ergonomic support systems. For example, electric transport devices equipped with automatic lifting systems can reduce the effort required to lift and lower heavy loads, improving safety and reducing operator fatigue. This feature is particularly useful in industrial and logistics applications where large or heavy goods need to be lifted and handled [11], and for the mobilization of patients in hospital settings so as to decrease the load on the operator [23]. Although less prominently, mention must also be made of the subcategory "Safety", for its relevance in daily life. In fact, inventions have been implemented, or intelligent devices, such as sensors, have been added to improve the safety of the trolley. In this way, such technologies help prevent accidents and assist the operator in driving maneuvers. Finally, the analysis of the results shows a clear prevalence of the subcategory "decreased workload" in the "increased safety" category of electric transport vehicles. This reflects the importance placed on operator safety and performance optimization in the design and development of modern electric transport devices. The implementation of technologies and features aimed at reducing the required physical effort and improving operator comfort and safety is key to promoting greater operational efficiency and a better electric forklift experience.

3.4. Number of Wheels

As Figure 5 depicts, it emerges that in the "Number of Wheels" category of electric carts, the predominant subcategory in both the total database (36%) and the subcategory (61%) is the one with four wheels. However, good percentages also emerged in the subcategories with two wheels and three wheels. The "four-wheeled" subcategory is the dominant choice among the electric transport vehicles identified in the research. This configuration offers superior stability and greater load capacity than the subcategories with fewer wheels. Four-wheel electric carts are commonly used in a wide range of industries, such as logistics, manufacturing, freight transportation, and more. They offer reliable stability and good maneuverability, allowing them to handle heavy loads and navigate smoothly in both open spaces and indoor environments. The subcategory "two-wheeled" has achieved a good percentage of use in both the total database and the partial category. Electric transport devices with two wheels are characterized by greater maneuverability and agility than those with four wheels. This configuration is often adopted in applications that require more flexible mobility, such as personal transportation, light load handling, or use in confined spaces. For example, electric monowheels are an example of a two-wheeled cart that offers a compact solution for personal mobility in urban settings [24]. The subcategory "three-wheeled" also showed a good utilization rate. Electric carts with three wheels offer a balance between

stability and maneuverability. This configuration is often chosen for specific applications, such as handling medium or light loads in confined spaces [25], and transportation of bats in golf course [26]. They can be adapted to meet the needs of specific sectors, such as the food industry or commercial distribution [27]. Although the subcategory "tracked" did not obtain a preponderant share, it is important to note that this configuration was considered in the research. Tracked electric transport devices are designed to tackle difficult or rough terrain, offering superior traction and greater stability on uneven surfaces. They are often used in industries such as agriculture [28], construction [29], and other applications where the ability to overcome obstacles or difficult terrain is critical [30]. In addition, in the context of electric transport vehicles, it is common for one or two wheels to be used to provide the necessary electric traction. This configuration allows electric power to be used to move the vehicle in an efficient and controlled manner. Figure 6 collects some examples of vehicles with different numbers of wheels.

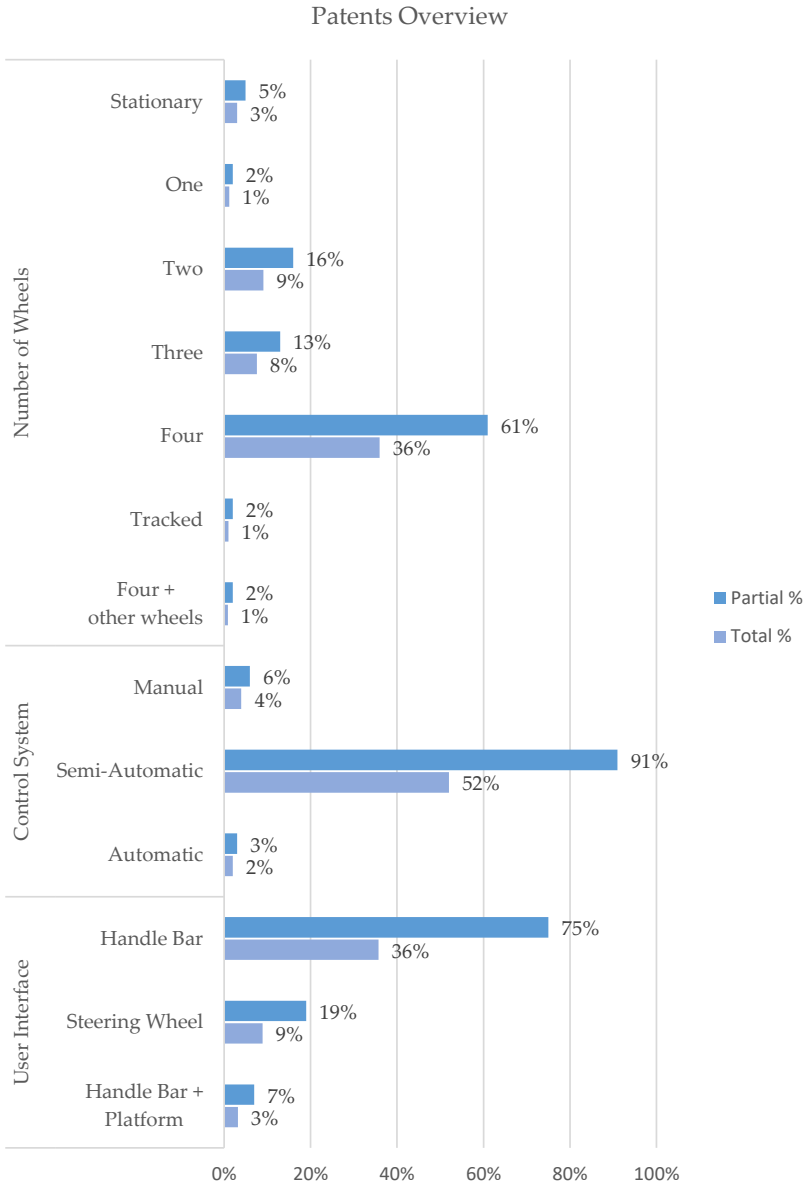


Figure 5. Distribution of patents by macro-categories and subcategories for the group referring to technical details and design solutions. The darker color represents the relative percentage value of the subcategory within the relative macro-category, while the lighter color represents the percentage value of the subcategory with respect to the total amount of analyzed patents.

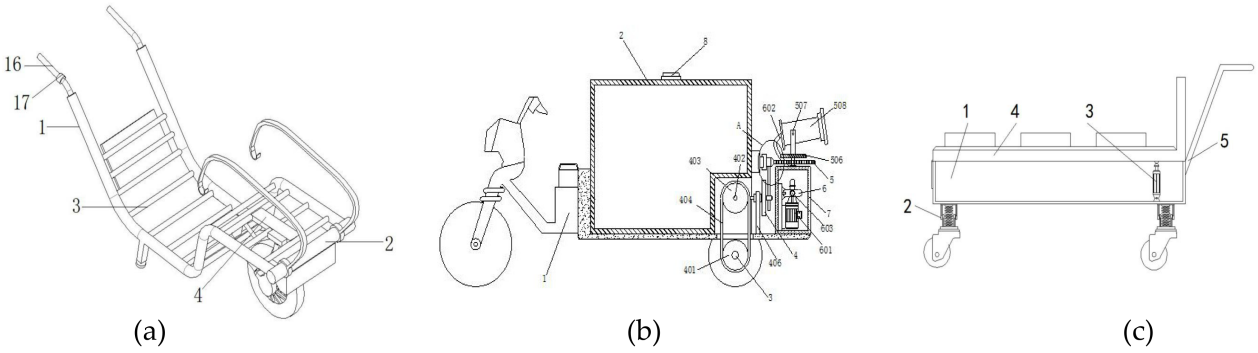


Figure 6. Examples of electric vehicles with different numbers of wheels: (**a**) one [31], (**b**) three [32], and (**c**) four wheels [33].

3.5. Control System

The results obtained for the "Control System" category, divided into manual, automatic, and semiautomatic, will be examined. As Figure 5 depicts, the preponderant control system category in both the total database and the partial category is semiautomatic systems. This evidence indicates a significant trend toward the adoption of control solutions that combine elements of automation and human intervention. They also allow the user to lighten the workload, such as in moving materials around a farm or in an agricultural field [34]. The high percentage, 52%, of semiautomatic control systems found in the total database suggests that such solutions are widely used and appreciated in the application domain. This could be attributed to their ability to combine the advantages of automated systems, such as efficiency and accuracy, with the essential role of human intervention in decision-making. In this way, there will always be human intervention, which will provide great safety, together with high levels of ergonomic comfort and usability for the user. Furthermore, the importance of semiautomatic systems is also emphasized within the partial category, with 91% indicating that their adoption is predominant even among the most advanced control systems. This implies that producers view semiautomatic systems as an effective solution for improving performance and efficiency of operators and users. The predominance of semiautomatic systems in the total database and partial category reflects the evolution of control technologies and the operational needs of the applications considered in the research. These results also indicate a potential for further development and improvement of semiautomatic control systems to better meet the specific needs of the contexts of use and to take full advantage of their benefits.

3.6. Interface with the User

Data collected in the conducted research show that in the "user interface" category of electric carts, the predominant subcategory in both the total (36%) and partial (75%) databases is "handlebar" (see Figure 5). This indicates that the handlebar is the preferred interface for users to control and manage electric trolleys. The handlebar represents an intuitive and convenient interface that allows users to easily control the direction and speed of the electric trolley. This type of interface is commonly used in a variety of applications, such as freight handling [35], personal transportation [36], and other activities that require precise navigation and comfortable driving [37]. Electric trolleys with handlebars provide users with a secure and comfortable grip, allowing precise control and a stable driving experience. The handlebars can be adjustable in height or tilt to suit users' individual preferences and needs. For example, electric carts used in warehouses and distribution centers often feature an adjustable and swiveling handlebar, allowing operators to maneuver easily in tight spaces and negotiate tight turns [38]. This type of handlebar offers greater maneuverability and precision when loading and unloading goods. Data also show that, less predominantly, some electric dumbbell trucks

can also be equipped with an integrated foot platform [39]. This additional feature allows the operator to find a comfortable position while driving, reducing fatigue, and improving overall ergonomics. However, the "steering wheel" was also found to be a significant choice among patents, with a remarkable percentage of use. There is partial percentage in the macro-category (19%). The steering wheel is a traditional and widely used interface in the automotive industry, offering familiar and intuitive control for driving vehicles. In electric transport devices, using the steering wheel as an interface allows users to have a greater sense of control over the direction and maneuverability of the truck. For example, electric carts used in environments, such as golf courses [40] or theme parks [40], can be equipped with a steering wheel to provide a more engaging and enjoyable driving experience. This type of interface is appreciated by users who want more interaction and control while operating the electric trolley.

3.7. Country of Validity

The results for the macro-category of patents, "Country of Validity" (see Figure 7) indicate that China is the country where a significant number of patents concerning electric carts have been filed and granted. China has established itself as a notable research and development hub for electric trolleys. Chinese companies have invested not-negligible resources in developing innovative technologies and designs to enhance the efficiency and performance of electric transport devices, resulting in a substantial number of patents [41,42]. In addition to China, other countries that have shown significant presence in this category include Japan, Korea, and Taiwan [43], reflecting the commitment of these nations to promoting technological innovation and competitiveness in the electric vehicle industry. In general, many Asian countries are recognized for their dedication to technological advancement. These nations have invested in research and development, fostering innovation ecosystems that encourage the emergence of new technologies and products. This has stimulated a high number of patent filings in these countries as companies seek to protect their discoveries [43]. Besides, Asian countries often boast a large base of highly developed, and competitive manufacturing industries. This creates a favorable environment for innovation and technology commercialization, encouraging companies to invest in research and new product development. Protecting their inventions through patent registration is crucial for success and competitiveness in the global market. This favorable scenario propels patent activity.

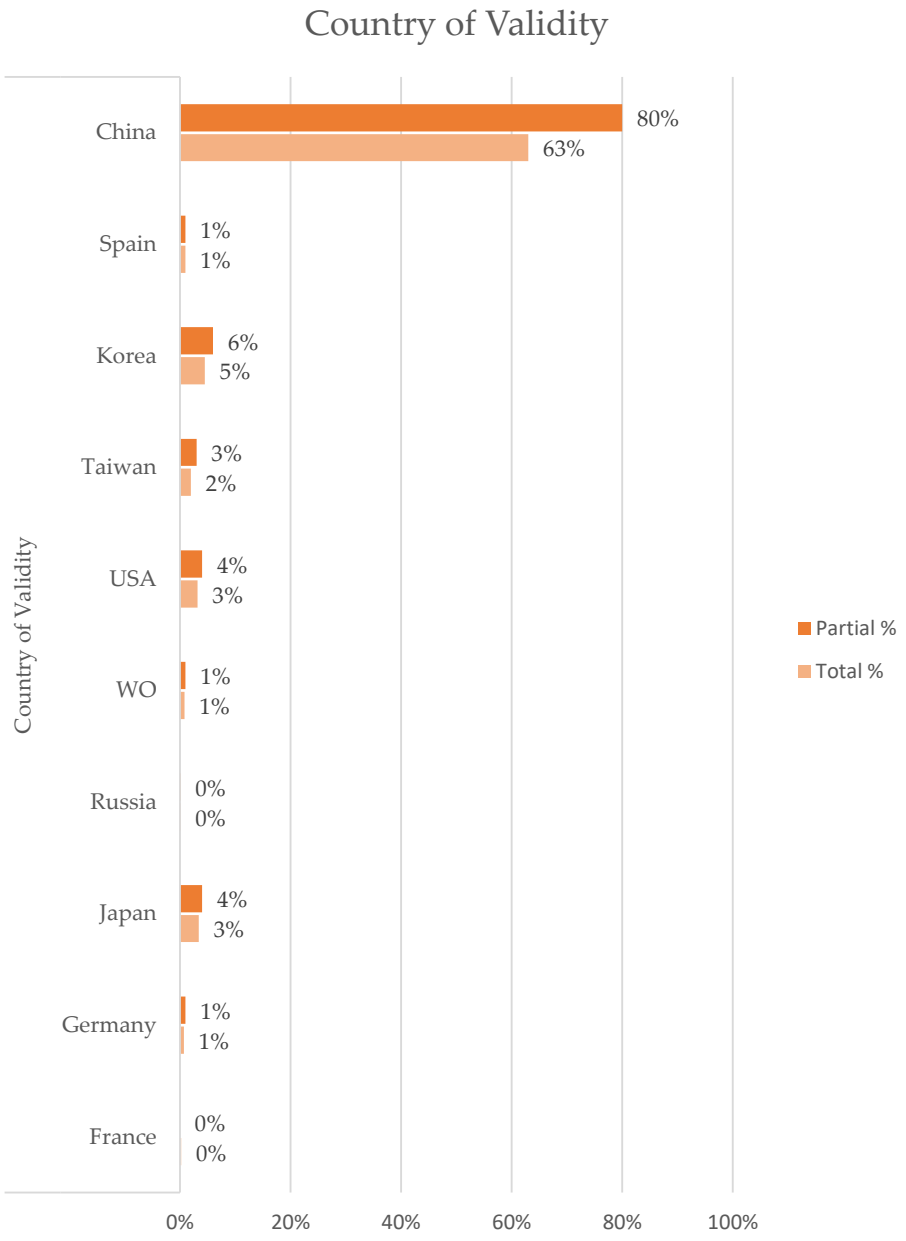


Figure 7. Distribution of patents by macro-categories and subcategories for the group referring to the countries of validity. The darker color represents the relative percentage value of the subcategory within the relative macro-category, while the lighter color represents the percentage value of the subcategory with respect to the total amount of analyzed patents.

4. Detailed Analysis

During qualitative research, significant results emerged that go beyond the main themes of study. "Out of Topics" provided interesting insights and innovative perspectives to further explore different areas. Particular attention was also devoted to the topics of "smart carts" and "smart devices", which could revolutionize daily activities by offering automated assistance and facilitating loading and transport operations. Furthermore, the analysis emphasized the significance of intelligent devices capable of adapting to user preferences and providing intuitive, personalized interactions. These results provided insights into the design of new solutions, allowing engineers and designers to consider user needs and overcome the limitations of existing solutions. The results show a wide range of ideas and proposed solutions, providing a broad knowledge base for future progress

and direction of research and development activities. Relevant and innovative patents were identified that represent sources of inspiration and potential opportunities for further development and practical applications.

The analysis of these patents over the years reveals that the evolution of electric carts has witnessed a fascinating progression, with trends shifting from the foundational aspects of cart functionality to the forefront of digitalization. Initially, the emphasis was on enhancing the basic performance and operational features of electric carts. As the industry recognized the need for more advanced and efficient solutions, the trajectory shifted toward integrating digital technologies. Currently, the main trend is related to the improvements in the world of digitalization. This refers to the integration of advanced technologies to enhance the performance and user experience of electric carts. Digital innovation, such as sophisticated software, contributes to real-time improvements in cart functionality.

4.1. Smart Devices

This discussion focuses on the 171 "Smart Devices" developed for electric transport vehicles as part of the conducted research. The incorporation of smart devices into electric carts and trolleys is an important development in the industry, as it enables improvements in the performance, efficiency, and safety of such vehicles. The smart devices identified in the research cover different areas of functionality and focus on different aspects of electric transport vehicles, as Figure 8 depicts. These devices offer a wide range of innovative solutions to make electric carts and trolleys more intelligent and interconnected, thereby improving their usability and overall performance. Among the identified smart devices, advanced monitoring and control systems are the most common [44]; they enable real-time data collection and analysis to monitor electric cart performance. These devices provide useful information on battery status [45] and other types of functionalities.

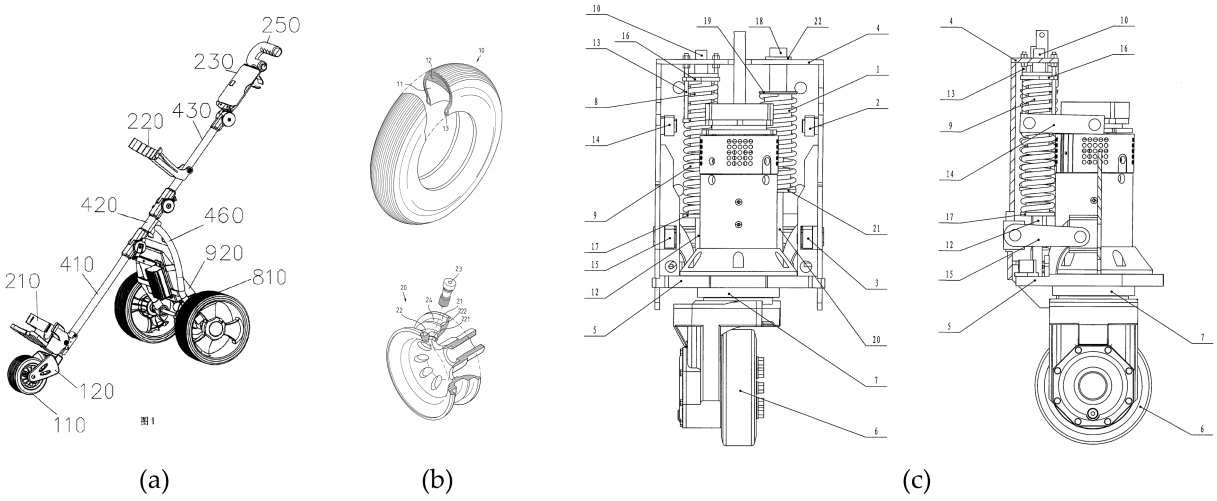


Figure 8. Examples of solutions for different functional purposes: (**a**) a structure for an electric golf cart [46], (**b**) a structure for a small tire suitable for electric carts and skateboards [47], and (**c**) a power suspension mechanism for an electric transport cart [48].

Another relevant category of intelligent devices is 'driver assistance systems', i.e., which integrate technologies such as sensors [49], cameras [50], and advanced algorithms [51] to provide assisted driving and accident-avoidance capabilities. These devices are designed to improve safety while operating electric transport vehicles by detecting obstacles [52] and warning of dangerous situations [53]. Intelligent devices have been identified that facilitate human–machine interaction, such as intuitive touch screens [54] and voice commands [55]. These devices simplify the use of electric carts and trolleys, allowing operators to quickly access information and functions, improving efficiency, and reducing workload [54]. Importantly, integrating smart devices into electric transport vehicles not only

improves operational performance but also contributes to greater sustainability and energy savings. For example, some smart devices enable optimization of battery use by monitoring and adjusting energy consumption in real time [45], thus ensuring longer battery life and autonomy. Also included under this macro-category are methods of controlling an electric trolley, based on a central controller [44], such as a microprocessor or microcontroller, receiving input from sensors and providing output to the vehicle's motors or actuators. Examples of these solutions are presented in Figure 9.

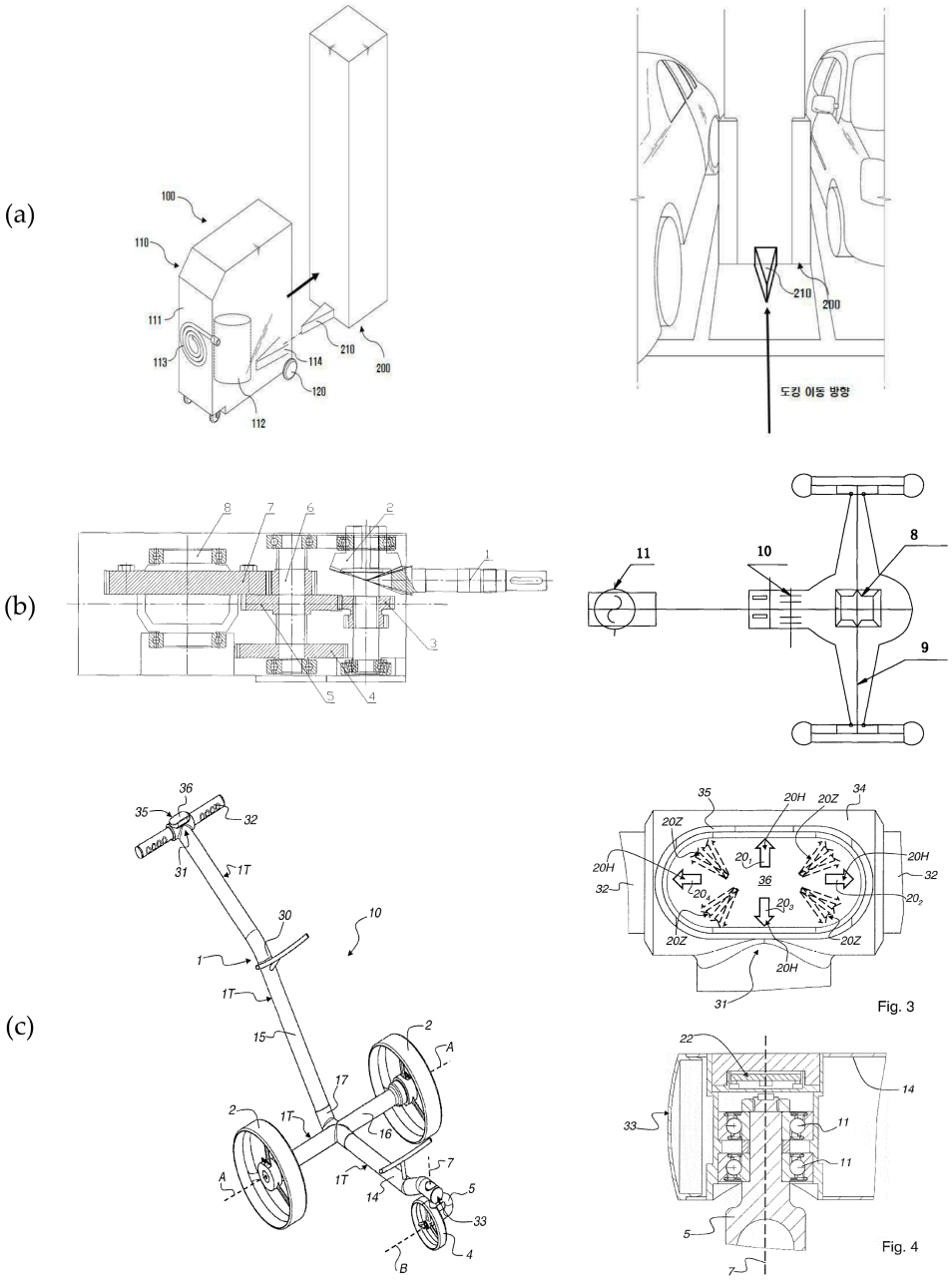


Figure 9. Examples of solutions for smart vehicles: (**a**) an electric cart providing alarms for obstacles [52], (**b**) an electric transport cart with two-gear mechanical and electronic speed change [56], and (**c**) an electric-driven trolley to transport golf bags, with sensors integrated in electric driven systems, like the handle [49].

4.2. Design Cues

Design cues are intended as all those 'non-intelligent' devices that could inspire the design of future carts, as they bring improvements to existing carts.The design of electric carts is a constantly evolving field, where the main goal is to improve the efficiency, safety, and overall performance of these vehicles. Within this broad area, as many as 248 design cues have been identified that offer useful ideas and suggestions for the development of innovative and functional electric transport devices. One of the main design cues concerns energy efficiency, a key issue for electric vehicles. To achieve greater efficiency, several solutions have been suggested. These include optimizing the drive system to reduce energy losses [57], using lightweight materials to reduce vehicle weight [58], and implementing energy recovery systems during braking or deceleration [59]. These solutions maximize vehicle range and reduce overall energy consumption. A crucial aspect in the design of electric transport vehicles is batteries. Recent developments in the field of batteries have led to significant improvements in energy storage capacity, weight reduction, and faster charging times [60]. Electric forklifts can benefit from these advanced technologies, which can increase vehicle range and reduce downtime due to recharging. Safety is of paramount importance for electric transport devices. Design cues in this area include protection against overloading [61], prevention of overheating [62], and safety warnings [63] to reduce the risk of accidents. Ergonomics is a key factor in the design of electric transport vehicles, as it affects the comfort and safety of operators. Design cues in this area include the ergonomic layout of controls [64], seating arrangements [65], and vibration and noise reduction [66] to ensure a more comfortable driving experience and reduce operator fatigue. Another important aspect is the adaptability of the trolley. In fact, an electric trolley can be designed to be adaptable to different types of objects or goods to be transported. The versatility of the trolley makes it possible to optimize the use of cargo space and improve the efficiency of handling operations.

5. Conclusions

The described study investigated the state of the technique on manual, semi-automatic, and automatic electric devices for transportation, through the analysis of the patent literature. In this sense, as tools for intellectual property protection, patents may provide precious insights into market-ready technological innovations, for instance, revealing trends and interests in the research and development efforts of companies. On the other hand, this aspect can also be seen as a limitation of the work: in fact, the limited time of validity of these documents often suggests that a patent is filed just when the innovative solution is close to the market stage rather than in the early stages of development. Consequently, a patent survey reasonably emphasizes technical innovations and solutions that may result in products from research over short time horizons.

To enrich the overview of the analyzed topic, the state of the art could also be explored, integrating the results of the patent survey with an analysis of scientific literature. To maintain consistency with the immediacy of technology transfer potential, scientific production as conference papers could likely be a more aligned source than scientific journal articles and reviews for direct comparison. Some suggestions can be found in articles, considering the patent activity in the electric vehicle industry, providing valuable information about innovation trends. For instance, a study by Ma et al. [67] analyzing EV-related patents from 1970 to 2016 found that battery charging and distribution technology is a major focus, with wireless charging emerging as a research frontier. Similarly, according to Schmitt et al. [68], worldwide patenting activity in the electric vehicle industry shows Europe as a significant market for electric vehicle technologies.Nonetheless, the purpose of the analysis was to outline a comprehensive overview of the state of the art, as a survey of the knowledge stated in this area from the analysis of filed patents, without assessing their legal validity. In fact, granted patents, patents not in force (such as invalid or expired patents), and patent applications were all analyzed in the same manner.

Some considerations can be outlined when considering the possible limitations of the applied method for the data selection. For instance, the words chosen to compose the search string represent a crucial aspect of the procedure. The selection of the specific keywords 'trolley' and 'cart' is grounded in their relevance to the field of electric transport vehicles. These terms are prevalent in patent literature, particularly in contexts involving material handling, retail, healthcare, and public transportation. The aim was to capture a broad spectrum of electric transport vehicles and their diverse applications. The historical and contemporary usages of these terms in patents influenced their selection, ensuring a comprehensive overview of technological advancements over time. These terms encompass a range of technological solutions, from basic electrically assisted carts to advanced automated trolleys, allowing for an analysis that spans varying levels of complexity and innovation. Preliminary reviews and expert consultations underscored the significance of these terms in capturing relevant patents. This informed the search strategy, striking a balance between focusing on pertinent patents and ensuring a broad capture of technological diversity within the field. The strategic inclusion of these terms aligns the dataset with the overarching objectives of the study, ensuring both relevance and breadth in the analysis, as the coherent IPC codes of the identified patents reveal.

Similarly, the analysis primarily focuses on patents and literature in the English language. While this might present a perceived limitation in terms of language diversity, English is widely recognized as the international language of science and technology. Many of the largest patent registration organizations, such as the United States Patent and Trademark Office (USPTO), the European Patent Office (EPO), and the World Intellectual Property Organization (WIPO), accept or require the submission of patent documents in English. Furthermore, even if a patent is initially filed in another language, it is often translated into English to facilitate the international understanding and dissemination of information. This is especially true for patents that have global interest or that are filed in multiple jurisdictions through processes like the Patent Cooperation Treaty. According to these considerations, we can expect that the exclusion criteria applied to the documents language may introduce a reasonably acceptable level of information loss.

Further analyses could include (i) investigating patents in force compared to patents not in force, (ii) analyzing inventors or applicants by type of organization (e.g., individual, private or public institution, company), and (iii) mapping patent applicants by geographic location, for instance for patents in force. These investigations could de facto examine various aspects of patenting, emphasizing different interests and purposes of analysis. For instance, evaluating the validity of patent families is a crucial step for companies to avoid or minimize the risk of infringement when launching new products. On the other hand, surveys on the type of institution of applicants or inventors may offer valuable insights for policymakers, for example, to enhance the impact of investments in research and development. Additional studies, such as evaluating the geographical location of patents in force, could eventually suggest areas of interest for investors in new productions and markets.

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Abbreviations

The following abbreviations are used in this manuscript:

EV	Electric Vehicles
IPC	International Patent Classification
MDPI	Multidisciplinary Digital Publishing Institute
WIPO	World Intellectual Property Organization

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