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Analysis of the Design of Lifting and Transporting Vehicles with a Variable Center of Gravity – A Literature and Patent Overview

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***Abstract* — *Due to today's economic problems, the demand for universal lifting and transporting vehicles with high efficiency is high in manufacturing plants, logistics centers, warehouses, etc. There are many problems that need to be solved in order to increase the efficiency of lifting and transporting vehicles. Maintaining and controlling their longitudinal and lateral balances during operation is one of the important issues that still need to be addressed. They also include reducing the turning radius of the vehicles and thereby increasing the efficiency of the vehicles, as well as industrial enterprises and warehouses. The article analyzes several types of patents and research papers related to the variable center of gravity. In this case, the study was divided into groups according to the proximity of the directions in the patents. The advantages and disadvantages of the development of lifting and transporting vehicles with adjustable gravity centers, as well as the work that needs to be done, were discussed.*

Keywords — *counterweight, the center of gravity, forklift, wheelbase.*

I. INTRODUCTION

The level of complex mechanization and automation of loading, unloading, transportation, and warehousing in industrial sectors is largely related to the level of specialized vehicles, like universal, well-known, and high-efficiency vehicles that can perform several tasks simultaneously. These vehicles differ from other types of vehicles by their compactness, manageability, small mass, much higher performance, low cost, and can cover its cost in a short period.

There are many types of lifting and transporting vehicles, as one of the most widely used in industrial sectors are forklifts and there is some statistical information about it. In the world, 1,493,271 forklifts were sold in 2019, from this number 647,229 units or 43.3% sold in Asia. China, as the biggest manufacturer and seller of forklifts in the world, sold 608,341 units in 2019; from this amount, 455.516 or 74.9% of forklifts were distributed to the domestic market [1].

Forklifts are mostly used in the construction industry, logistic centers, or warehouses as workhorses [2]. They have different types, forms, and sizes, as well as lifting capacity. The Industrial forklift models lifting capacity is about 23 tons, and they always have the potential for injury. The United States Bureau of Labor Statistics (BLS) data has indicated that there were nearly 8,000 forklift-related injuries in 2018. Occupational Safety and Health Administration (OSHA) reported that per year average of 34900 injuries by accident occur with forklifts and industrial trucks, and 25% of the roll-overs are caused to death [3]. Of the approximately 850,000 forklifts in the United States, 11% will be involved in some form of the accident [4].

Summarizing the statistics above, it can be predicted the number of forklifts produced and sold in the world in the last 10 years. That means very large numbers. Now, if these numbers are calculated as a percentage of accidents in America in static numbers, it is an indication of how much work still needs to be done on forklifts.

The main technical characteristics of lifting and transporting vehicles are lifting capacity, nominal load lifting and lowering speed, the maximum speed with and without load, outline dimensions, turning radius, wheelbase, vehicle mass, and its distribution to the front and rear wheels (with and without load), the required width of the corridor at the turning conditions, technical and operational efficiency, operating mode, accuracy indicators, and energy sources can be specified. At the same time, the fact that the center of mass is in a safe zone during the lifting and transportation of load is an essential factor not only for its balance but also for the safety of the driver. For this reason, many international scientific and practical studies have been carried out to determine the center of gravity of lifting and transporting vehicles [5]–[9] and analyze their static and dynamic balances [10]–[16].

In order to operate forklifts more adaptable in narrow aisles, their wheelbase is constructed smaller than cars [17]. Stability rectangle of the car adopted to stability triangle for forklifts because of the construction of the forklift [18]. At the same time forklift with a small wheelbase has some disadvantages, like decreasing the stability triangle and increasing the braking distance during the working and running conditions. This increases the possibility of deviation of the center of gravity from the safety zone of the forklift in Fig. 1 [19]. The deviation of the center of gravity of the forklift out of the equilibrium triangle causes the vehicle to tip over.

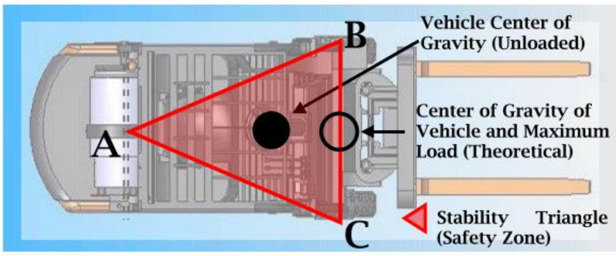

Fig. 1. Center of gravity and stability triangle of forklift truck [19]

Despite the scientific research that has been done, the shortcomings of today's forklifts, such as the large wheelbase, inflexibility in narrow lanes, and large turning radius, have an impact on the quality of the vehicle. In order to overcome the above disadvantages, several patents were analyzed. As a result, the following constructions were divided into several groups according to the method of solving the above problems.

II. USING METHODS

A. Vehicles with variable wheelbase.

Several designs have been developed to increase the load capacity and stability of the car by changing the wheelbase. Of these, Vitale et al. [24] proposed the design of a vehicle with elongated chassis is shown in Fig. 2. In this case, the frame of the vehicle consists of two parts; the second part of the frame is operatively connected with the first part. The second part of the frame moves along the first part of the frame, thereby increasing the length of the chassis. The rear gate of the first vehicle body is raised and opened, and then the second vehicle body is joined with the open part of the first vehicle body; the raised part of the first vehicle body closes the upper part of the second vehicle body. The car's chassis is extended when there is an additional load or passenger is required. The disadvantage of this design is that all of the above work is done manually and takes a certain amount of time.

The design of an electric wheelchair with variable axle distance in Fig. 3 is done by Hu Daguang et al. [25]. In this design, the frame of the wheelchair is divided into two parts, consisting of front and rear parts. The front and rear parts of the frame are connected to each other and provided with wheels. The driving device that changes the distance between two axles is arranged between those two parts. The driving device is mounted on the front part, and its moving part is connected to the rear axle and the rear part of the frame, which is connected to the link connecting these axles. The purpose of the invention is to extend the wheelbase in order to control the gravity center of a wheelchair while climbing and retract to its smallest position while on horizontal surfaces. The disadvantage of this design is that during the movement, the transition from three wheels to the four wheels or vice versa has not been fully studied and may cause difficulties during a control.

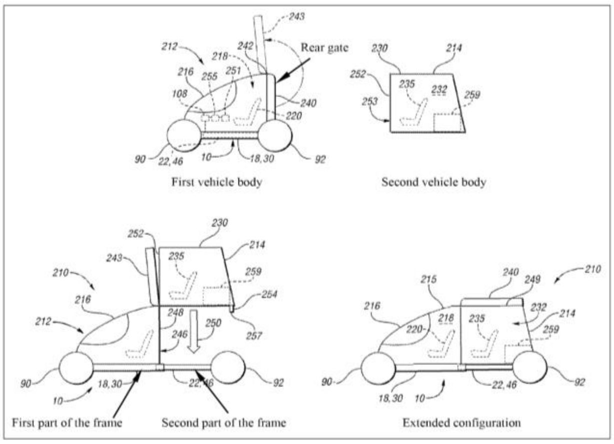

Fig. 2. Vitale's [24] expendable vehicle (annotations added).

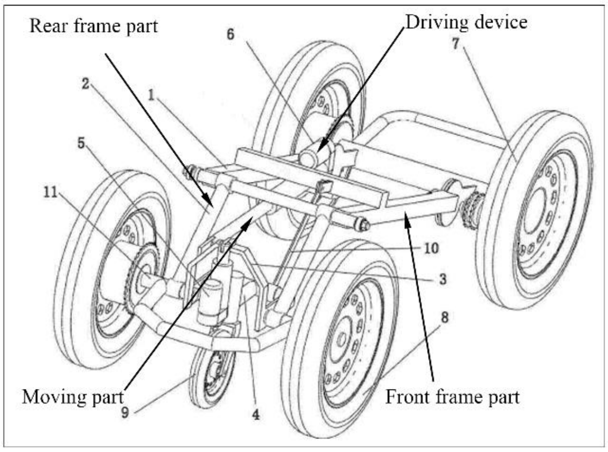

Fig. 3. Electric wheelchair with variable wheelbase [25], (annotations added).

The design by David in 1980 is proposed variable wheelbase road truck shown in Fig. 4 [26]. In this design, the rear and front axles of the road truck are fixed at specific points along with the rigid chassis. The difference of this truck is that it is equipped with an additional movable axle that can move behind the rear axle longitudinal beam of the rigid chassis. Extension of the additional movable axle can be increased the load-bearing capacity of the truck and return its previous position while unloading. The additional movable axle can move in the vertical direction when the truck with loaded or in dangerous corners. The main drawback in this work is that retracting of the movable axle during the unloading process has not been fully studied.

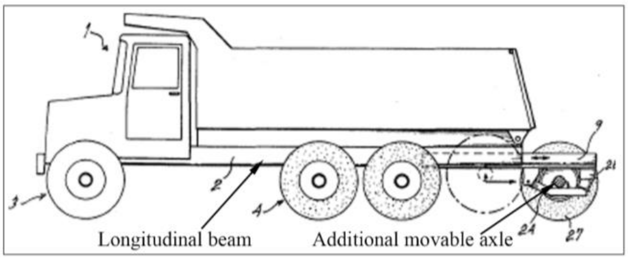

Fig. 4. David's [26] road truck (annotations added).

Donaldson's [27] telescopic lifting vehicle with a variable wheelbase, shown in Fig. 5, consists of two parts. The front body part is attached to the front group of wheels, which characterize the wheelbase of the vehicle, and the rear body part is attached to the rear group of wheels. Both body parts of the vehicle can move comparatively to each other and parallel to the vehicle's longitudinal length, which can lengthen or shorten the wheelbase. The boom of the vehicle connected pivotally to the base. Boom rises when the wheelbase is in a retracted position and declines when the wheelbase is in an extended position. The vehicle is provided with an extra counterweight, and it can move vertically and in the longitudinal direction of the vehicle in retracted and extended positions. This characterizes the vertical and longitudinal movement of the center of mass of the vehicle. The main disadvantage of the design is the increased height of the center of mass when lifting the load, and it has a large turning radius when moving without a load.

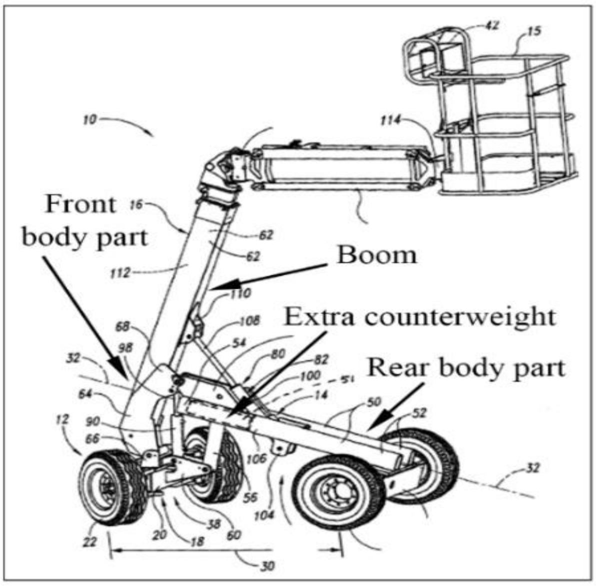

Fig. 5. Donaldson's [27] lifting vehicle (annotations added).

In Priefert's [28] study on telescoping tractor frames, further summaries of designs can be found in Fig. 6. This telescopic elongated tractor frame consists of two cylindrical frame parts whereof can extend along with the vehicle's lengthwise and connect front and rear wheel axles. The frame is stretched to lift heavy loads or shortened to improve maneuverability. For removing the tractor from the muddy place, the frame may also be extended and retracted repeatedly. The drawback of this work is increasing the turning radius of the tractor in a loading position.

Fig. 7 shows the design of a forklift with a variable wheelbase, which includes the mainframe, cab, counterweight, and rear wheels [29]. There is an additional movable frame on the mainframe of the forklift that can move along the axis of the mainframe. The additional movable frame is provided with a hydraulic cylinder to move relative to the mainframe. The moving frame is located at the bottom of the cab and counterweight and extends to the rear side as a continuation of the mainframe, thereby changing the base between the wheels, creating a variable center gravity at the rear end of the additional movable frame installed rear axle, which is moved backward in proportion to the weight of the load.

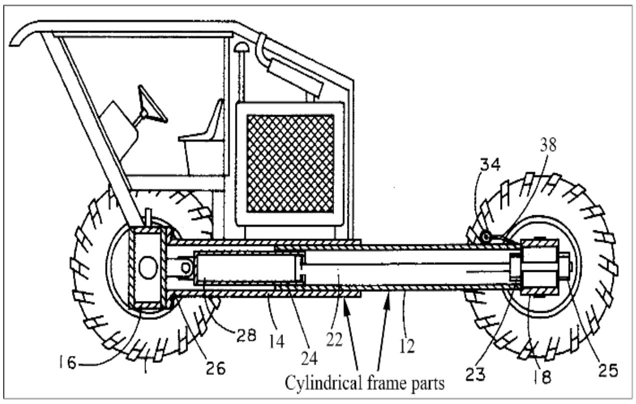

Fig. 6. Priefert's [28] telescoping tractor (annotations added).

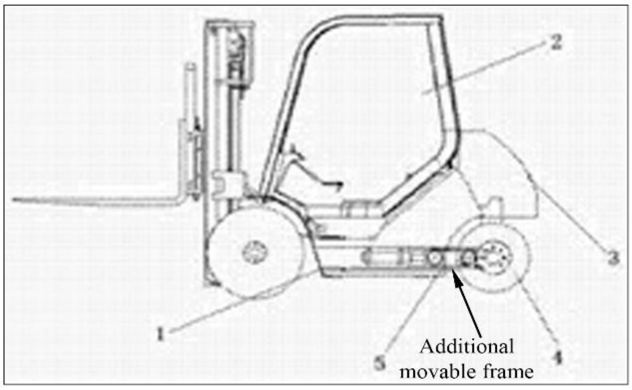

Fig. 7. Forklift with a variable wheelbase [29], (annotations added).

Following one is Andrew's [30] variable wheelbase vehicle in Fig. 8. This structure has front and rear ends which can move relative to each other. The engine that drives the vehicle is attached to the body and connected to the body elements. The driving motor is installed in the elongated part of the vehicle, and while running of the drive motor vehicle wheelbase is capable of extending or retracting. The extension of the wheelbase allows increasing the vehicle's load capacity and overturning moment. At the same time, it reduces the possibility of turning in a narrow aisle when the car is loaded.

The next structure [31] in Fig. 9 proposed a design that would increase the lifting capacity and counterweight of a forklift by moving the front axle forward. In this case, the rear axle, which controls the steering wheel, is provided with a counterweight, and the front axle is connected to the main body of the vehicle by a roller those moves in the guide with limited length. It can be actuated by hydraulic cylinders. When the wheelbase is reduced, the flexibility of the forklift is improved, and when the wheelbase is increased, the torque of the counterweight is increased, the lifting capacity of the forklift as well. The main disadvantage of this design is that the strength of the forklift when transporting these heavy loads is directly related to the strength of the roller and the shaft used in it, and at the same time, increases the turning radius of the vehicle.

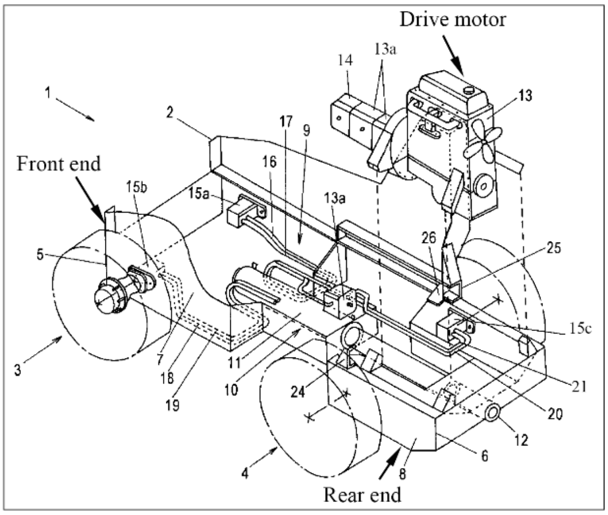

Fig. 8. Andrew's [30] variable wheelbase vehicle (annotations added).

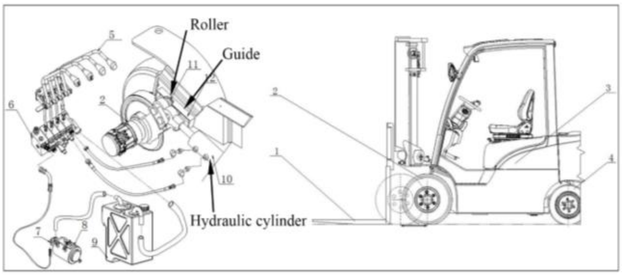

Fig. 9. Variable wheelbase forklift [31], (annotations added).

B. Vehicles with an adjustable counterweight

A flexible standard frame for a forklift was invented by Hoyt [32], shown in Fig. 10. The main idea is that as a result of increasing the length of the frame allows displacing the counterweight in several different positions along the length of the vehicle, which increases the torque of the counterweight. The Adjustable counterweight consists of interchangeable parts, and it serves to reduce the cost of construction and allows improving the frame of ordinary forklifts. This conception has an additional removable frame that consists of L-shaped horizontal and vertical legs. The L-shaped part is attached to the mainframe of the forklift, and the horizontal leg is capable of increasing the length of the mainframe. The vertical leg is located away from the mainframe and lies in the same direction. By two threaded bushings with different lengths and bolts, the counterweight can be secured in four different positions relative to the mainframe of the vehicle. However, the invention is designed to carry a certain type of cargo, and it takes a certain amount of time to displace the counterweight.

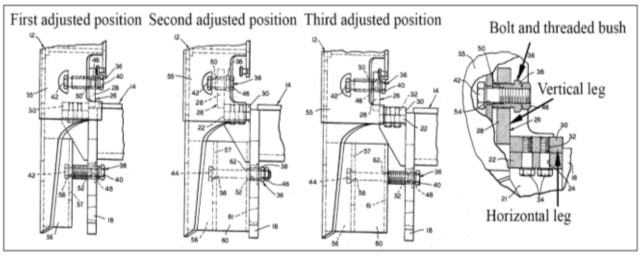

Fig. 10. Hoyt's [32] counterweight (annotations added).

Similar to the above case is presented by Lee [33] in Fig. 11, which is intended to displace the counterweight in several positions for a certain load. The counterweight of this invention touches the back of the vehicle and moves at regular intervals. Several threaded holes are drilled in the back of the vehicle, and the counterweight is pushed to the rear and bolted to these holes. Simultaneously, the bolt at the bottom increases in length in parallel with the displacement at the top. This balances the vehicle and prevents it from rolling. The main disadvantages of this type of counterweight are that it can change its position for a specific purpose, is difficult to change, it can be done manually, and takes enough time.

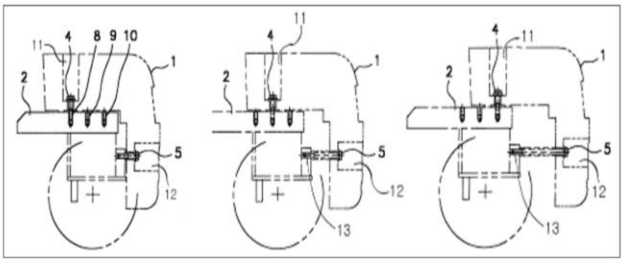

Fig. 11. Lee's [33] movable counterweight.

The following invention in Fig. 12 by Cosby [34] is proposed to move the counterweight to the rear side of the forklift. The adjustable counterweight is designed to be mounted on the rear of the vehicle and can displace backward at certain distances through grooves in the body relative to the rear of the vehicle's chassis. Two back legs of the overhead guard are mounted to counterweight; therefore, it is capable of extending backward. When the counterweight changes its position relative to the chassis, the overhead guard also increases its length through the extension section at the top. The Extension section has several adjustment openings in certain distances, which extension is performed through that adjustment openings. However, all of the above work is done manually.

Sun [35] provided more improved work than the above construction in Fig. 13. The purpose of this invention is to adjust the gravity center of the vehicle accordingly when lifting and transporting products of different types and weights. The counterweight of the forklift and its flexible part, which counterweight consists of two parts, the upper part of the lower part is equipped with a ventilation hole, and the two sides of the hole are equipped with mechanisms that provide a flexible gravity center. The mechanism for adjusting the flexible gravity center consists of rack gear, gear, worm screw, and worm gear. The main disadvantage of this design is the complexity of the design and the manual adjustment of the counterweight.

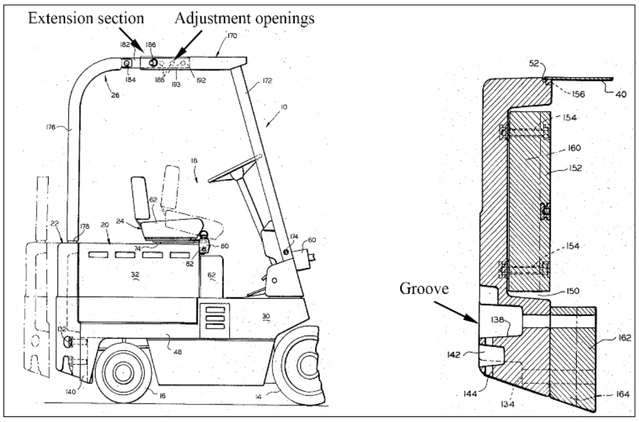

Fig. 12. Cosby's [34] forklift, (annotations added).

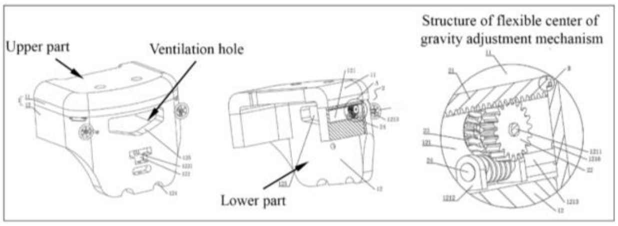

Fig. 13. Sun's [35] adjustable counterweight, (annotations added).

In contrast to the above works, in the next design [36], automated control is used for adjusting the center of gravity of the forklift in Fig. 14. An important aspect of this invention is that it is equipped with a rectangular-shaped additional counterweight. An additional counterweight is freely mounted horizontally on a guide under the frame and driven by a hydraulic cylinder along the longitudinal axis of the vehicle. In order to increase the passability of the forklift in bad climatic conditions (ice, slush, rain, etc.), the additional counterweight is actuated to the side of the driving axle. For increasing the load capacity of the vehicle, the additional counterweight is moved until the vertical counterweight. The drawback of this invention is the difficulty of moving the additional counterweight along with the guides. Here another updated version [37] of this work is provided by the same inventors in Fig. 15. Distinguish of this work is that the additional counterweight is mounted in the guide on the bearings and provided with the additional load from outside of the guide by embedded elements. It can increase the load capacity of the forklift from 1.5 to 16 tons by installing additional loads.

Marnon et al. [38] proposed a new design for a forklift with an automated variable center of gravity. The main purpose of this work is to move the counterweight from the first position to the second position in a short time with low energy consumption and, at the same time, increase the weight-bearing capacity of the vehicle. The rear of the structure is designed to unload and reload heavy counterweight in Fig. 16. The mechanism is driven by a hydraulic cylinder. When the shaft of the hydraulic cylinder is pulled inwards, the counterweight moves outwards, while in the reverse position, the counterweight return to the previous position. However, the complexity of the design and a large number of links may negatively impact the strength of the vehicle.

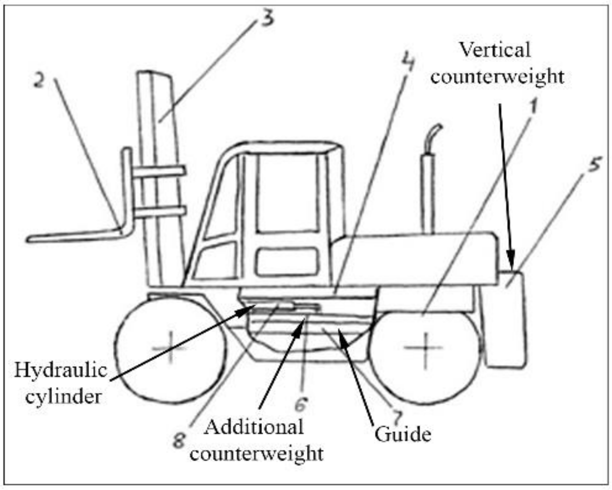

Fig. 14. Forklift with additional counterweight [36], (annotations added).

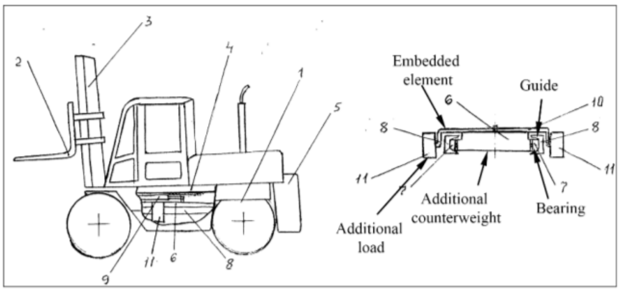

Fig. 15. Forklift with additional counterweight and load [37], (annotations added).

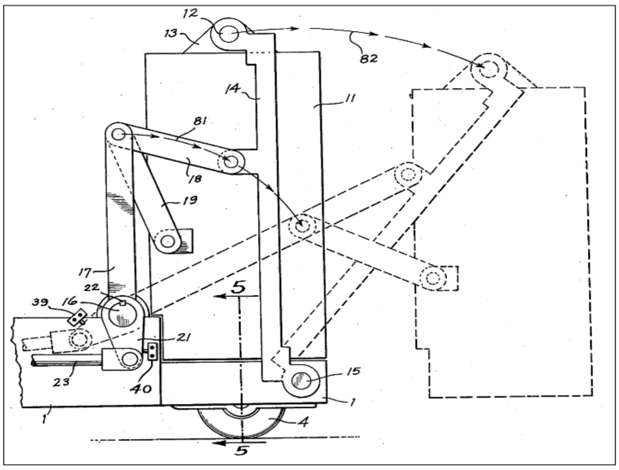

Fig. 16. Marnon's [38] adjustable counterweight.

The main object of the invention below is to provide the vehicle with shiftable balance [39], which means to provide manual or automatic control of the balance when the balance is not in the normal position during the lifting of the load, in Fig. 17. When the vehicle is moving on the sloping road or on a downgrade, the overturning moment encountered increases significantly. At that time, the box of the battery moves rearward automatically to provide stability. The machine is equipped with a switch, and during this load lifting, when the machine reaches the load lifting norm, the switch moves the hydraulic cylinder and provides balance. Using batteries as a counterbalance may negatively impact their working durability.

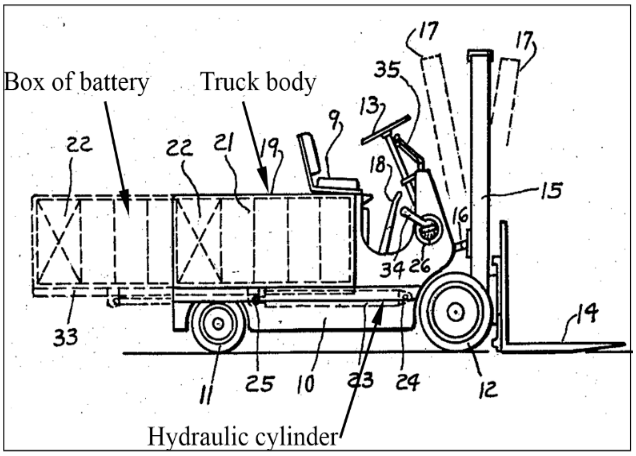

Fig. 17. Locke's [39] forklift, (annotations added).

Ming Su et al. [40] proposed a much more compact design than previous inventions. The purpose of this work is to increase the lifting capacity of the vehicle using a flexible counterweight device designed for the internal combustion engine and electric forklifts shown in Fig. 18. The rear of the machine consists of two welded guide rails, moving rollers on the rails (4 rollers on each rail), counterweight, base plate fastened to the counterweight with screws, hydraulic cylinder, and a plate for holding the hydraulic cylinder, mounted on the back with screws. The shaft of the hydraulic cylinder is attached to the counterweight. The rollers moving on the rails are fixed to the support plate using a bearing. Here, the counterweight is pushed forward or backward using a hydraulic cylinder depending on the weight of the load being carried. The main shortcoming of this design is the difficulty of the repairing process.

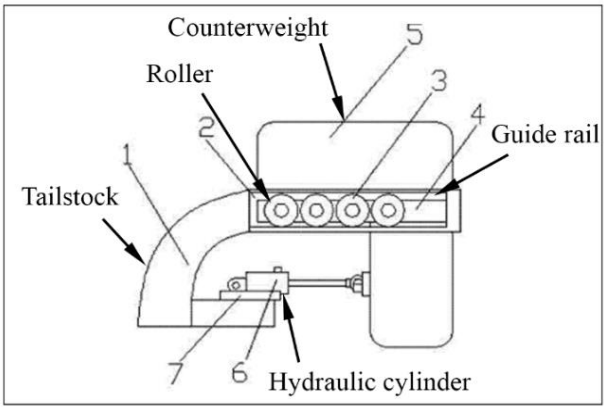

Fig. 18. An adjustable counterweight for forklift [40] (annotations added).

Fig. 19 [41] presents a design that can increase the load-bearing capacity of the vehicle without increasing its cost. Here is the simple structure of a forklift that is flexible to loading. It consists of two guide rails attached to the rear axle and symmetrical along the longitudinal axis of the vehicle, rollers, and counterweight on it, and a hydraulic cylinder for adjusting the counterweight according to the requirement. This structure is designed for lifting and transporting heavy loads on small forklifts.

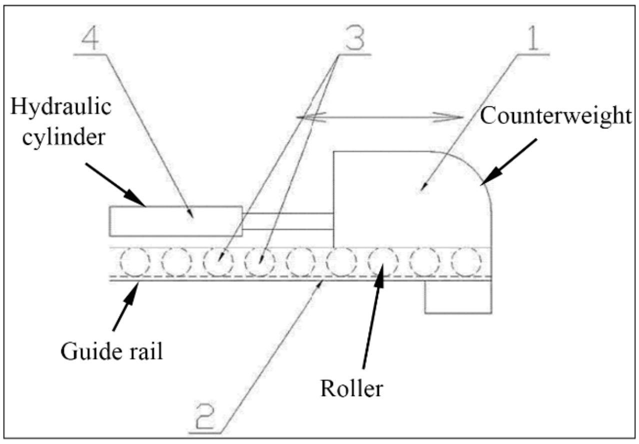

Fig. 19. Zhang's [41] forklift with adjustable load-bearing capacity (annotations added).

Another schematic construction is presented by Japanese inventors Noriyuki and Kensuke [42]. The design in Fig. 20 is very simple, and it means that when the load-lifting mechanism moves forward, the counterweight of the vehicle moves backward proportionally in a longitudinal direction of the vehicle. When lifting the load onto the vehicle body, the process is reversed. In this way, the gravity center of the vehicle stays at the safe point.

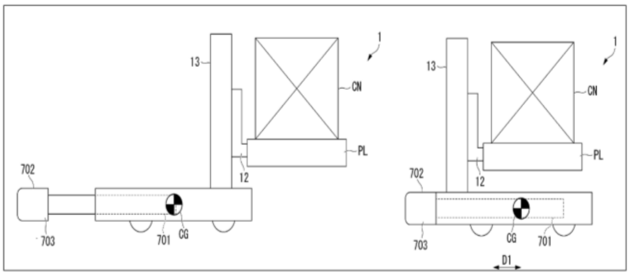

Fig. 20. Forklift with a flexible center of gravity [42].

Couberly [43] gave a different proposal than the above constructions in Fig. 21, which is additional loads are mounted on the frame between the front, and rear axles, and these additional loads are as a flexible counterweight slide between the front and rear axles. When it is necessary to increase the traction force, the flexible counterweight moves towards the front axle, and when lifting the load, it moves backward the rear axle. However, these additional loads require extra energy consumption and reduce the service life of some parts of the vehicle.

In the next work, a forklift with a telescopic boom and interchangeable counterweight is shown in Fig. 22 [44]. In this case, the counterweight of the forklift is located at the rear of the vehicle, and the lifting part is located at the front. One end of a pair of booms of the lifting device is connected to the uprights with hinges at the same side counterweight compartment of the vehicle. Each of the uprights consists of two plates, between which is placed an element made of heavy material, and this pair of uprights is designed to perform the first counterweight function for the vehicle. The counterweight compartment is located between these two uprights, and up to two special loads can be placed on this compartment. These two special loads act as the second and third counterweights of the forklift and increase the load-carrying capacity. The main disadvantage of this work is loading and unloading these special loads manually into the compartment.

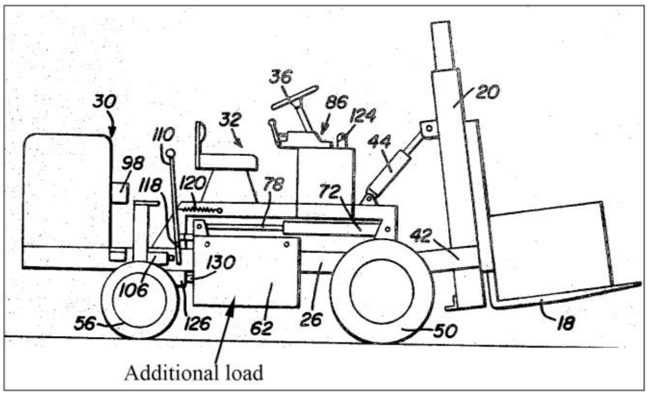

Fig. 21. Couberly's [43] counterbalance for the forklift (annotations added).

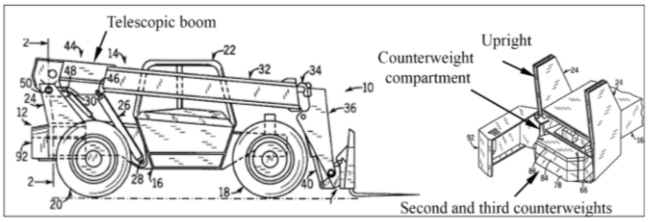

Fig. 22. Hoebelheinrich's forklift-type vehicle [44], (annotations added).

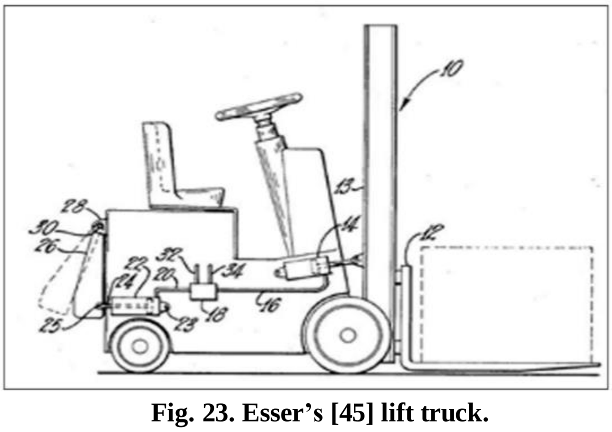

Fig. 23. Esser's [45] lift truck.

Esser [45] presented more exceptional work than others. The design, in Fig. 23, he proposes a counterweight forklift that provides stability under the different loading conditions. That is, the counterweight is adjusted proportionally to the weight of the load being lifted. More precisely, the pressure in the hydraulic cylinder increases according to the weight of the load being lifted. When the value of weight reaches a certain amount, the valve begins to pressurize the hydraulic cylinder, which is connected to the counterweight, and in this way, the stability of the forklift is ensured. The difference between this work and others is that the counterweight is tilted back to a certain angle. The disadvantage is that the flexibility of the center of gravity is directly related to the length of the hydraulic cylinder.

C. Universal

In this section, we will look at some of the more universal inventions, one of which is the construction created by Erker [46]. Fig. 24 shows the construction of a longitudinally and transversely extending frame. The vehicle frame consisting of two members, front and rear members, has flexible telescopic channels and is fastened using bolts. The total length of the vehicle frame and wheelbase are ensured by fastening the channel parts using a combination of holes in the frame. Through the flexible frame members, it will be possible to supply different sizes of the battery compartment and thus the required power. The channel-shaped spacers ensure the strength of the frame. The rear axle is mounted to the rear member of the frame, and the wheelbase can also be changed by changing the length of the frame. The shoulder is increased by controlling the dimensions of the frame. This increases the effect of the counterweight torque. The main disadvantage of this design is that all the above works require manual labor and extra time, increasing the turning radius of the machine as a result of increasing the distance between the front and rear axles.

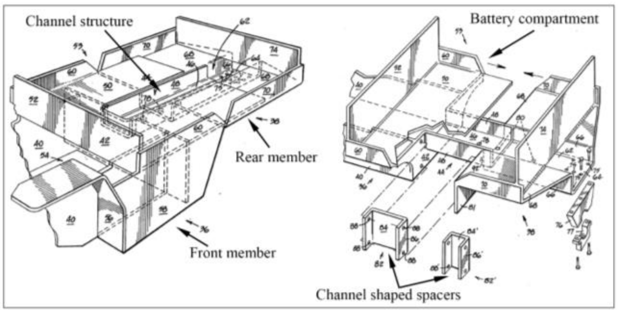

Fig. 24. Erker's [46] expandable frame (annotations added).

Cao et al. [47] gave a solution to maintain longitudinal and transverse balance when transporting loads with flexible gravity centers in Fig. 25. The elements of this invention are the vehicle chassis, the counterweight, the hydraulic cylinders placed on the right and left sides, and the third one is mounted inside of the counterweight. The third hydraulic cylinder, mounted inside the counterweight, has adjustable weights on both ends. These loads move in T-shaped grooves in the counterweight. One end of the two side hydraulic cylinders is attached to the vehicle, and the other end is attached to the top of the two sides of the counterweight. The lowest end of the counterweight is connected to the chassis using a hinge. Through the movement of the piston rods of these two hydraulic cylinders, the upper part of the counterweight is tilted backward, and thus the total center of gravity of the vehicle is pushed back. When transporting dissymmetrical loads, the center of gravity toward which side deviates, and the internal hydraulic cylinder acts in the opposite direction to the deviation, ensuring that the center of gravity of the vehicle is on the axis of symmetry. The disadvantage of this invention is increasing the vehicle's lifting capacity depends on the length of the hydraulic cylinders on both sides.

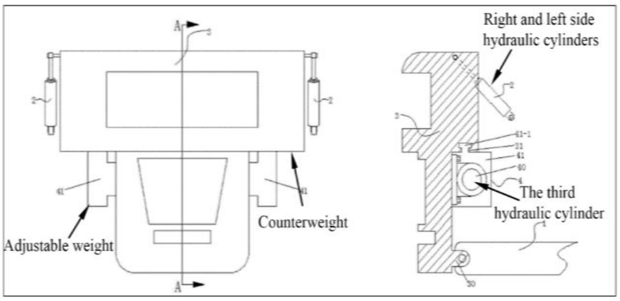

Fig. 25. Cao's [47] flexible gravity center forklift (annotations added).

The design [48] in Fig. 26 can be seen as a complex solution for several types of cases and at the same time allows to carry nonstandard loads. The variable center of gravity counterweight for a forklift is characterized by the following: on the inner wall of the counterweight has a sliding part B, and it is connected with sliding part A which is mounted to the vehicle body. The slider part A is provided with a support beam in the middle, and the lowest part of the support is attached to the vehicle frame. The vehicle is equipped with a hydraulic cylinder that propels the counterweight, with one end attached to the frame and the other end connected to the inside of the counterweight. The upper surface of the counterweight is provided with a bounding column, and it keeps a double-deck bearing plate. Bearing plates are equipped with hooks. Hooks are provided with additional loads when carried nonstandard loads. The lowest part of the counterweight has a supporting leg and a wheel that touches the ground at the end. It allows keeping the counterweight in the horizontal position. The main drawbacks of this work are the complexity of this design, the manual hanging of loads on both sides when needed, and the fact that the rear wheel can cause unexpected shocks to the vehicle when it is moving on uneven surfaces and cause serious damage to the structure.

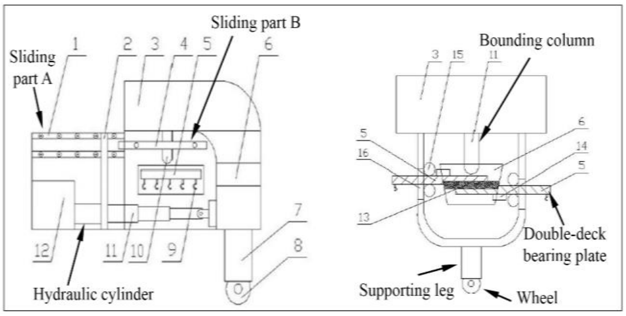

Fig. 26. Counterweight with variable center of gravity[48], (annotations added).

A patent for the unusual design of a high lift truck was filed by Magni [49]. Fig. 27 shows a truck with a mobile chassis, which has a platform that can slide forward and backward. The telescopic extension boom moves forward or backward along with the sliding platform. The moving chassis is equipped with two necessary sensors that provide information about the initial and final position of the platform in the horizontal direction. The lower part of the boom is connected to the platform and moves horizontally together with it, while the boom itself has the property of elongation to lift the load to the desired height. The movement of the Counterweight is related to the movement of the platform. If the counterweight moves to one side, the platform moves in the opposite direction. Counterweight also changes its position accordingly in order to maintain the balance of the truck during boom elongation. A truck equipped with a chassis that moves on wheels or crawlers.

Osswald et al. [50] offered a complex invention with high versatility, safety, and efficiency in an elongated framework vehicle in Fig. 28. The vehicle consists of flexible rear and front parts and has a frame that extends or retracts relative to each other. The engine is mounted on the back of the frame. The vehicle is equipped with an electro-hydraulic part that moves the moving part of the frame forward or backward. A microprocessor controller with a sensor in the electro-hydraulic system independently controls extension and retraction of the frame, the balance of the vehicle, and operate and steering of the wheels in diverse modes. The vehicle is equipped with a sensor that informs about the weight falling on the back of the frame depending on the load being lifted. When the back part of the vehicle frames backward, the torque of the counterweight increases, and it accepts as a secondary counterweight of the vehicle. The second counterweight is controlled according to the signal given by the sensor. Each joint of the lifting lever is extended using multi-stage telescopic hydraulic cylinders and is equipped with a single-axis inclinometer. Fork members and implement attachment plate of the forklift is equipped with crisscrossed shape elements that allow moving forward or backward.

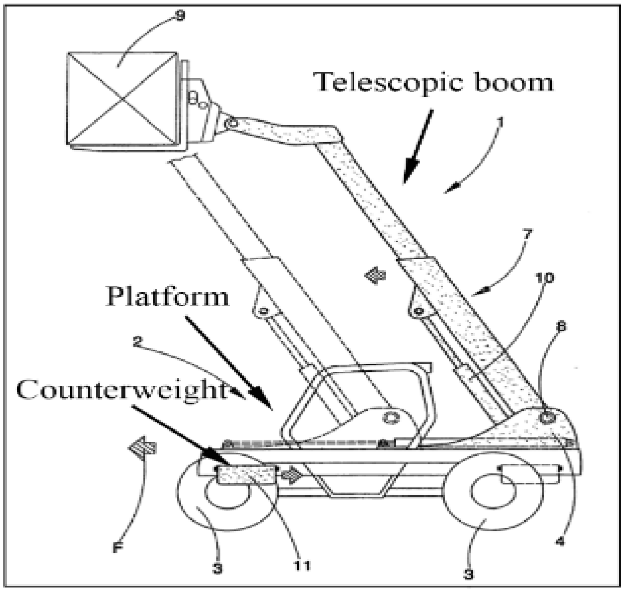

Fig. 27. Magni's [49] high lift truck (annotations added).

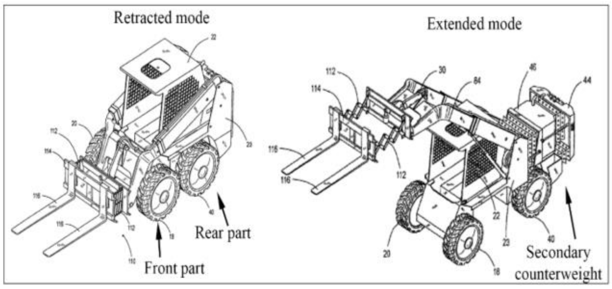

Fig. 27. Oswald's [50] work vehicle (annotations added).

III. DISCUSSION AND CONCLUSION

Several types of forklift designs have emerged over the past century. The quantity of the forklift with adjustable center of gravity patents has increased considerably over the past decade. However, there are very few working physical examples that are specified available based on the open sources. Essential prototype forklifts with adjustable center of gravity have been discussed in this review, and to date, among these designs, few of them are used.

The top leading companies [51] are improving lifting and transporting vehicles, and special forklifts are still undergoing development. The main key points of development of the forklifts are using energy-saving technology and renewable energy sources, with high stability, working efficiency, safety, and flexibility. Among all of the published sources, there is no concept of the exceptional combination for these specifications.

All of the concepts discussed above are designed to create a flexible gravity center of the forklift and other types of vehicles in order to provide stability while lifting and carrying different types of loads. Common shortcomings of these concepts include the complexity of the design, the difficulty of maintenance, the lack of automation, and the negative effects of some elements on the overall structural strength of the vehicle.

As a result of the analysis of these methods, can make the following conclusions:

1. The constructions presented in the first method are envisaged to increase the load-carrying capacity of the lifting and to transport vehicles by lengthening the wheelbase. A common problem with these designs is that the increasing the turning radius of the vehicle and inability to change wheelbase while driving;
2. The main part of the constructions given in the second method can be seen to be the manual execution of the counterweight retraction work and backward in limited positions, which are defined in the construction. In some concepts the increasing the load capacity of the vehicle through changing the counterweight position is directly related to the length of the hydraulic cylinder rod;
3. Despite the universality of the third method, they have some drawbacks like the modification of some of them can be done manually and the complexity of the concept or low efficiency of the developments.

Most of the structures in the above three groups are specialized to carry standard loads on flat surfaces, which can cause problems on sloping surfaces or non-standard loads. The purpose of these developments is mainly to maintain the longitudinal stability of the lifting and transporting vehicles.

Patents related to the construction of lifting and transporting vehicles with the variable center of gravity were studied, and innovative ideas in them were analyzed. The results of the analysis show that the demand for structures with a variable center of gravity is mainly invented due to the last decades, and the main part of them have registered patents from the USA and China. This suggests that over the past decade, there has been an increase in demand for lifting and transporting vehicles with compact, energy-efficient, variable gravity centers that perform several functions in industrial plants, warehouses, logistics centers, and similar organizations. Therefore, the creation of modern designs of universal load-lifting and transportation machines with a flexible center of gravity, energy-efficient automatic control of energy consumption, the hybrid energy source is one of the current issues. An essential step forward for lifting and transporting vehicles is to demonstrate the claimed high working efficiencies through an adjustable gravity center.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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