

## LIFTING MANIPULATORS FOR GARBAGES

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**Abstract** - The paper begins with a short history of development on the recycling and waste gathering vehicles since the First World War. The lifting and getting off the bins, to and from the body of special waste trucks, by some planar linkage – manipulators are studied. These lifting manipulators are equipped with gripper systems in order to load and unload the bins. Several kinematical schemas of type mono– and bi-mobile manipulators are analyzed, these being driven by one or two linear actuators. The kinematical geometry of these planar manipulators by means of scale drawing of the kinematical schema is displayed. Both lifting and getting off phases of waste bins were considered. Two solutions for a better efficiency and a green environment have been proposed. The second one is using an electric powered driving transmission. Finally, a modeling and simulation case of the lifting manipulator is presented.

**Keywords:** lifting manipulator, kinematical schemas, mobilities, simulation

### 1. INTRODUCTION

The development of lifting manipulators for loading and unloading the waste freight into and from specialized trucks has not been treated so much in literature [2]. One of the best reference titles on bin lifting automotive history is “The photographic archive of waste trucks” by John B. Montville [4] that presents the development of garbage gathering vehicles since First World War to nowadays.

The first waste vehicles had an open top part of the body to collect the garbage though they were not specially designed to perform this task. By 1920 about twenty garbage trucks with closed carriage were accomplished in Great Britain. This model of truck had a simply manipulator which consisted of two bars to lift the bin until it unloads the waste by rotation into the body. Also in 1920, the first rotate body truck for waste collecting had been developed in Germany. The advantage of this type was a bigger quantity of garbage that can be loaded in cleaner conditions into a greater carriage. First truck carriage with outer bunker had been made in 1929 and the rear loading body with waste compactor in 1938. This principle of rear loading compactor carriage is the most used in present, even if at that time the waste bins were manually lifted and unloaded. Other models of waste trucks are with side (1947) or front (1955) loading.

### 2. WASTE BINS AND LOADING MECHANISMS

The waste is collected in special containers or bins [3], of diverse sizes being made of steel (for larger dimensions) or plastic (fig. 1 and 2).

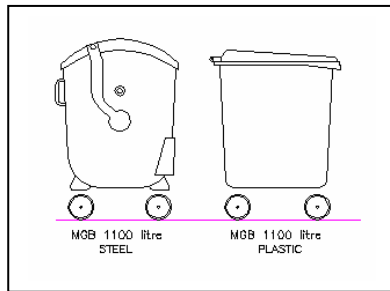


Fig. 1 Waste bins of steel or plastic

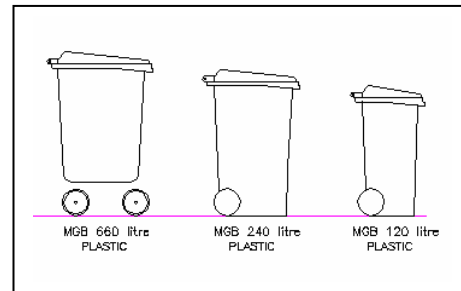


Fig. 2 Waste bins of plastic

After the mechanical loading of the waste (fig. 4) from bin into the receiving bunker of truck, the garbage is pushed into the main compartment of carriage as it can be seen in figure 3.

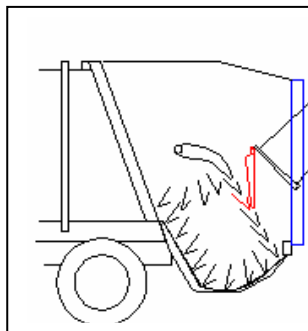


Fig. 3 Waste loading process

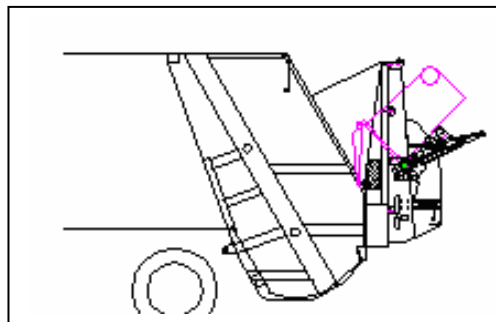


Fig. 4 Mechanical bin lifting

These bin lifting mechanisms (fig. 4) represent mono-mobile or bi-mobile manipulators [1] that grasp the bin, lift it until the receiving bunker level and lean it until the waste begin to fall into bunker. Once the bin is rotated by over 90 degrees from initial position, the bin opens by itself maintaining the lid in vertical position (fig. 3 or 4) and the waste is unloaded.

### 3. MONO-MOBILE LIFTING MANIPULATORS

Let's consider a mono-mobile lifting mechanism for heavy containers (fig. 5). This manipulator is a planar mechanism [1] that consists of one closed kinematical contour with hydraulic cylinder and another kinematical contour which is alternatively open in lifting phase or closed in waste unloading phase.

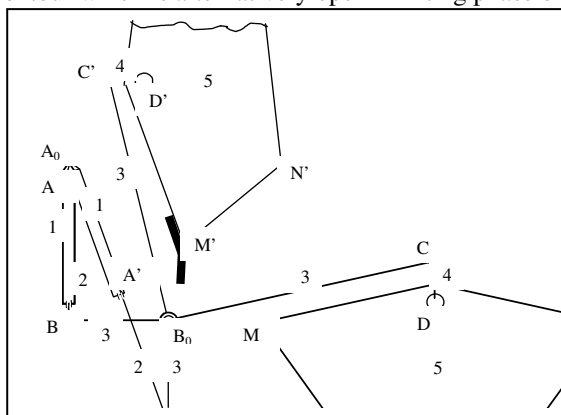


Fig. 5 Mono-mobile lifting manipulator for heavy containers

Initially, the rotate cylinder 1 of manipulator is in vertical position (thick line - fig. 5) having the piston 2 at top of it so that the rocker 3 has segment  $BB_0$  in horizontal position. Bar 4 is linked to the container 5 by a hook which allows an easy hanging of it and, also, a rotation of it in unloading phase (thin line - fig. 5). In final position (thin line - fig. 5) the piston 2 is at bottom of cylinder 1 and the container 5 leans with point  $M$  (now  $M'$ ) on a fixed point of carriage, the open kinematical chain formed of 3, 4 and 5 element becoming closed ( $B_0 C' D' M'$ ). In lifting phase the mechanism mobility results by using the following formula P. Antonescu [1]:

$$M = \sum_{m=1}^5 mC_m - \sum_{r=2}^6 rN_r \quad (1)$$

In this phase all six kinematical joints are mono-mobile ( $m = 1$ ) and there is only one closed loop of rank 3 ( $r = 3$ ), so that  $N_3 = 1$ . Therefore, by formula (1) results:  $M = 1 \times 6 - 3 \times 1 = 3$

Among these three mobilities (DOF) only one is active (controllable) – actuator (1+2). The others two mobilities are passive – rotation of bar 4 related to joint  $C$  and rotation of container 5 about joint  $D$ .

In the second phase there are two closed loops of rank 3, six joints of class 1 and one joint of class 2, resulting:  $M = 1 \times 6 + 2 \times 1 - 3 \times 2 = 2$ , but only one is active!

To manipulate light bins of plastic (fig. 2 and dashed line – fig. 6) it is used a mono-mobile planar mechanism with two closed kinematical contours, the first one having the actuator as rotate cylinder and the second one being a rotate jointed quadrilateral (fig. 6).

The kinematical scheme of manipulator has been represented in two limit positions, the bottom one displayed with continuous thick line (initial position) and the top one with continuous thin line (final position).

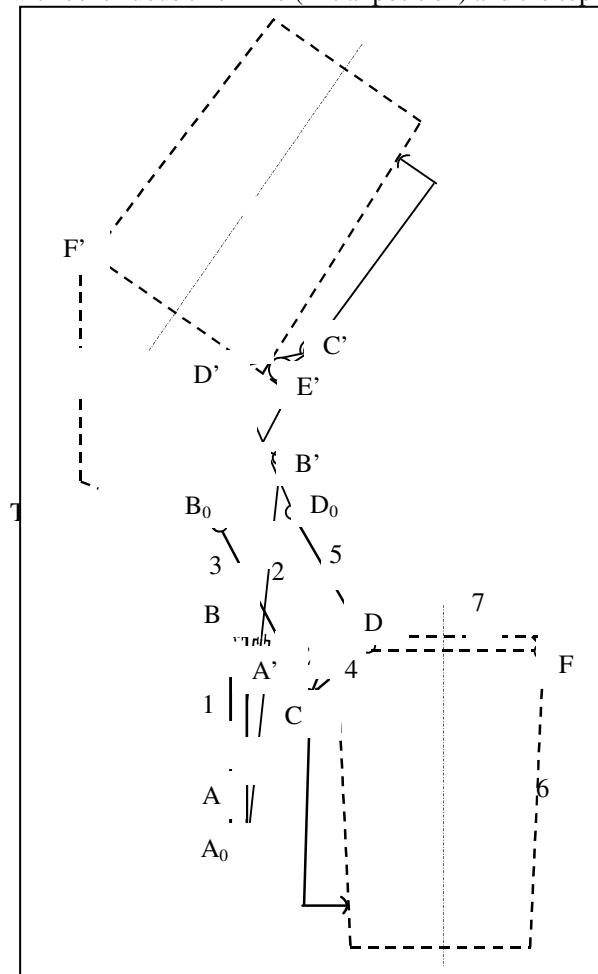


Fig. 6 Mono-mobile lifting manipulator for light bins

There are three fixed axes on the truck body  $A_0$ ,  $B_0$  and  $D_0$ . In the initial position (bin grasping) the cylinder 1 and piston 2 are in vertical position with the minimum length  $A_0B$ . Bar 4 has two mobile rotate joints  $C$  and  $D$ , and also the rotate joint  $E$  by which the bin 6 is positioned. In order to obtain the final position (waste unloading) the piston 2 slides into cylinder 1 to the end of stroke, the length  $A_0B'$  being maximum (fig. 6).

It can be observed that in initial position the rotate jointed quadrilateral  $B_0CDD_0$  is convex and in the final position it becomes concave ( $B_0C'D'D_0$ ), the two rockers 3 and 5 being crossed.

As it was mentioned in previous chapter, the bin 6 opens itself by maintaining the lid 7 in vertical position, this being linked to 6 by a rotate joint  $F'$ .

$$M = 1 \times 7 - 3 \times 2 = 1$$

This type of mechanism (fig. 6) allows 130-145 degrees rotation of the bin, being the most used lifting manipulator in street sanitation.

Of course, these mono-mobile manipulators (fig. 5 and 6) are achieved as double mobile structures operating in parallel planes (on both carriage sides). Therefore, the two hydraulic actuators must be synchronized in order to lift the bin(s) properly.

In the case of light bins (fig. 2), the manipulator lifts two or three plastic bins in the same time by using a horizontal bar (joint  $E$  in fig. 6) which links the two parallel mechanisms. On this connecting bar there are catching systems mounted, they being equipped with safety devices on manipulated bins.

#### 4. BI-MOBILE LIFTING MANIPULATORS

The bi-mobile lifting manipulators operate in the same conditions as mono-mobile ones, being double systems mounted in parallel planes, between them the waste bins being lifted and unloaded. The actuation of these mechanisms is provided by four hydraulic cylinders, each two of them in one working plane.

Let's now consider a bi-mobile lifting manipulator with rotate jointed parallelogram (fig. 7). The two cylinders work as following: one actuator drives in the first manipulating phase (bin lifting – bottom and middle positions) and the other actuator drives in the second phase (bin rotation – top position). This has the advantage of maintaining the bin vertically in the first phase, the movement being a circular sliding (in the same plane).

This bi-mobile mechanism (figure 7) has the first mobility obtained by actuator (1+2) (linked to element 6 by rotate joint  $A$  and to element 3 by rotate joint  $C$ ) and the second mobility obtained by actuator (7+8) (linked to truck body by rotate joint  $I_0$  and to element 6 by rotate joint  $J$ ).

The mobility is checked by formula (1):  $M = 1 \times 11 - 3 \times 3 = 2$ . In the first phase, when element 6 is static, the piston 2 slides into cylinder 1 until the stroke  $s_{21} = BB' = CC'$  is complete. Therefore, the bar 4 (by which the bin 9 is sustained) executes a circular sliding reaching the vertical  $E'F'$  position.

In the second phase, with the actuator (1+2) blocked ( $AB'C'$ ), the actuator (7+8) begins to drive by sliding the piston 8 into cylinder 7 until the stroke is  $s_{87} = II' = I_0J - I_0J'$ . During this phase the element 6 rotates as a rigid body, together with elements 1, 2, 3, 4 (9) and 5, around the rotate joint  $A_0$  by 130 degrees.

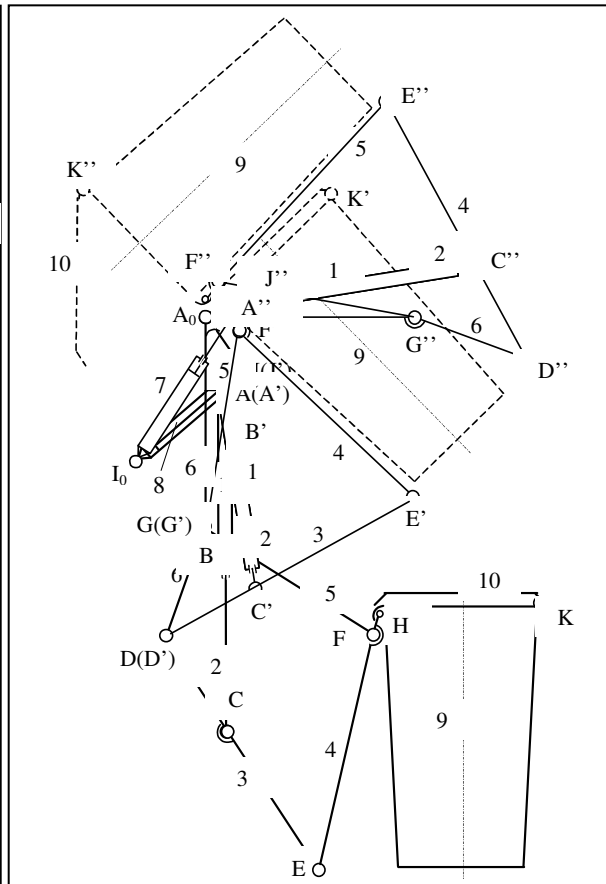
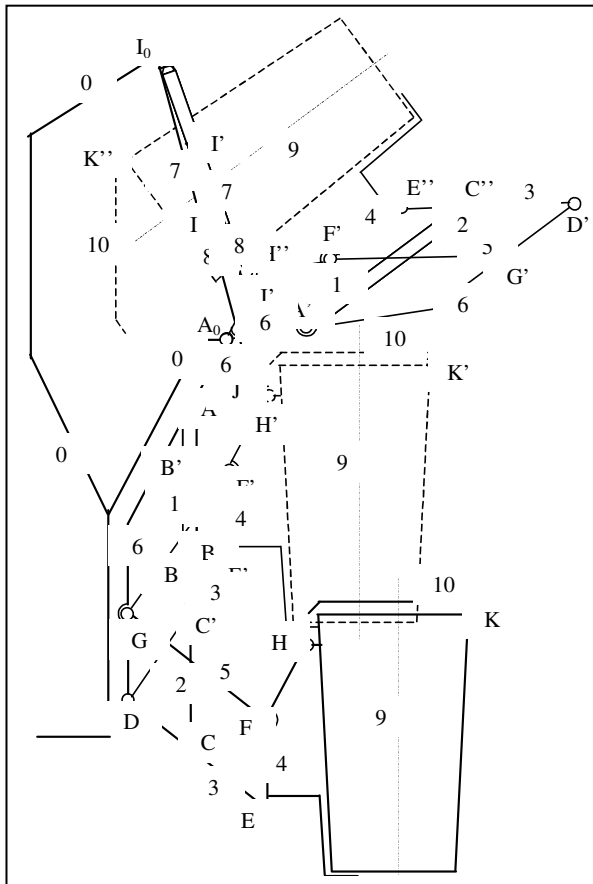


Fig. 7 Bi-mobile lifting manipulator with parallelogram Fig. 8 Bi-mobile lifting manipulator with quadrilateral

As it was explained in the previous case the bin lid 10 remains in vertical position, allowing the waste to fall into the receiving bunker of truck.

After the bin is completely unloaded, the actuator (7+8) slides at maximum extended position  $I_0J$  and then the actuator (1+2), once it reaches the vertical position, extends to maximum stroke  $AC = s_{21max}$ .

Further, we consider a bi-mobile lifting manipulator with rotate jointed quadrilateral (fig. 8). This may be called as general case comparing with the last one (fig. 7) because in the first phase the bin is lifted and rotated to about 45 degrees, and in the second phase it continues to rotate to extra 90 degrees.

The position of fixed rotate joint  $I_0$  of the second actuator lies under the fixed rotate joint  $A_0$  on truck body. This is an advantage regarding the length of hydraulic actuator-supplying pipes: closer actuators – shorter supplying tubes.

In initial position of the first phase the kinematical schema of manipulator (fig. 8) is drawn by continuous thick line (including the bin). The actuator (1+2) by cylinder 1 is rotate jointed to the bar 6 (which is rotate jointed to carriage by fixed point  $A_0$ ) and by piston 2 to the rocker 3 which is also rotate jointed to the bars 6 and 4. The bars 6, 3, 4 and 5 form a rotate jointed quadrilateral having “the base” 6 and 3 as driving element which is actuated by (1+2).

The kinematical schema (fig. 8) in the final position of the first phase is drawn by continuous thin line and the bin 9 by dashed thin line. During this phase from  $DEFG$  position the quadrilateral gets to  $D'E'F'G'$  position, where the bin 9 is rotated to about 45 degrees.

In the second phase the actuator (1+2) is blocked in retreated position ( $A'B'C'$ ) so that the quadrilateral becomes as one unitary element, with no movements among its bars, which, together with bar 6, is rotate jointed in the fixed point  $A_0$ . Now, the actuator (7+8) takeovers the command, having the cylinder 7 rotate jointed in the fixed point  $I_0$  on truck body, and the piston 8 linked to element 6 in point  $J$ .

The mobility is checked by formula (1):  $M = 1 \times 11 - 3 \times 3 = 2$ . In the final position of second phase the manipulator is represented by continuous thin line (fig. 8) using the following notations:  $A''$ ,  $C''$ ,  $D''$ ,  $E''$ ,  $F''$ ,  $G''$  and  $K''$ . In this position the bin 9 is rotated to extra 90 degrees so that the bin lid 10 takes a vertical position allowing the waste to fall into receiving bunker.

## 5. LOOKING FOR A BETTER EFFICIENCY AND A GREEN WORLD

Let's reconsider the mono-mobile lifting manipulator presented in chapter III (fig. 6). It can be observed that the length between the fixed joint  $B_0$  and the direction  $AB$ , traced by actuator (1+2), is very short related to the length  $BB_0$ . Therefore, it requires a strong hydraulic force to drive the actuator, especially at the beginning of the lifting stroke.

In order to decrease this actuation force and therefore to increase the mechanism efficiency, we propose a new way for mounting this mono-mobile lifting manipulator (fig. 9). By assembling its elements up-side down, we obtained a longer length for the actuation torque, about four times bigger, so that the lifting force in actuator (1+2) is much smaller especially at the beginning of stroke.

More than that, the lean of the waste bin can be controlled by changing the length  $B_0D_0$ . Thus, if this increases, the bin will tilt to a greater angle and doing so a better emptiness being possible.

Nevertheless, we considered that the rotate jointed quadrilateral  $B_0CDD_0$  is a double-crank type (fig. 9) having the side  $B_0D_0$  the shortest of all.

This means that the crank existing condition can be applied on bars 3 and 5 [1]:  $B_0D_0 + B_0C \leq D_0D + CD$

The intermediary position of the quadrilateral corresponds to the overlapped sides  $B_0D_0$  and  $B_0C$ , in which case for bar 4 the notation  $C^*D^*$  have been used. The mobility for this lifting manipulator is the same as the original, being calculated by formula (1):  $M = 1 \times 7 - 3 \times 2 = 1$

Nowadays, everyone is looking for some clean air to breathe. A solution for this is a waste truck having the lifting bin manipulator actuated by electrical motors. The problem in this case, like on any electrical automobile, is where can we take enough electrical power from? Since the waste trucks, generally, drive into the cities, would not be a problem. Every building and recycling area could have some plugs to supply unlimited power to waste trucks. Therefore, a lifting manipulator powered by outside electrical energy could be a solution!

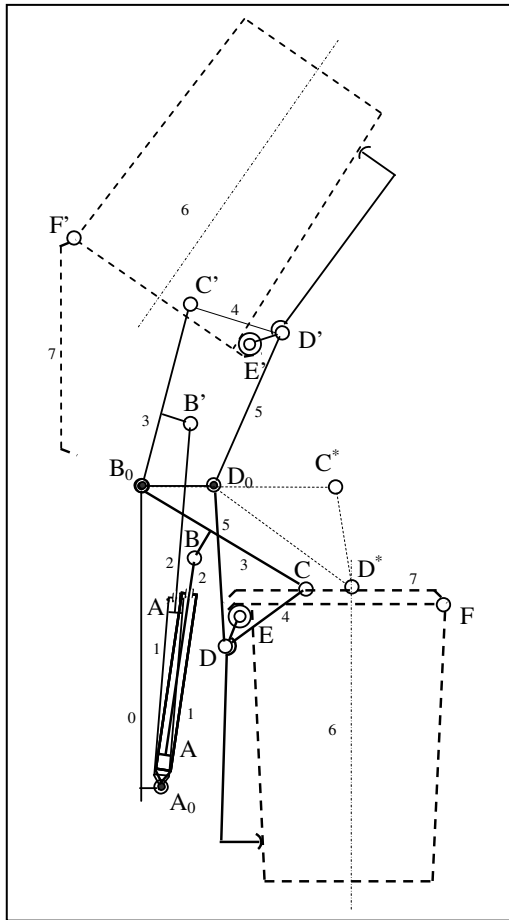


Fig. 9 Mono-mobile lifting manipulator with improved efficiency

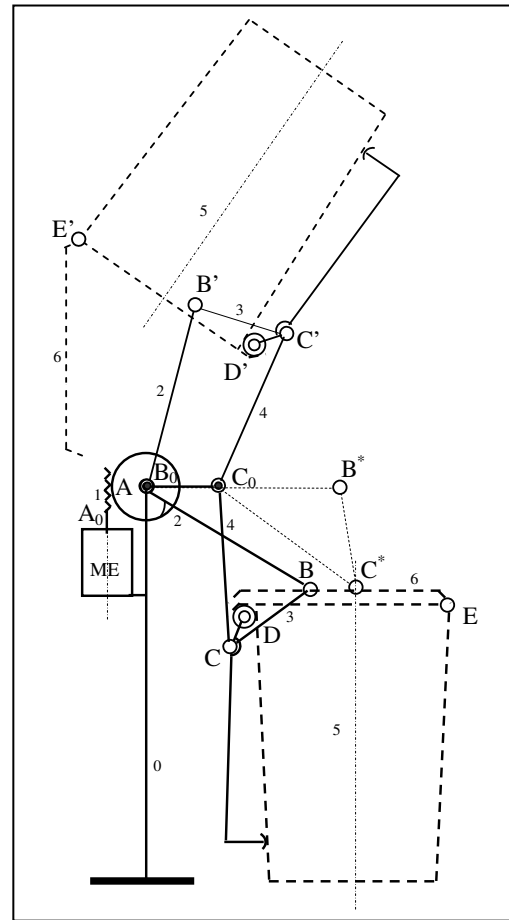


Fig.10 Electric powered mono-mobile lifting manipulator

Having this in mind, we propose a simply electrical driving solution for the lifting manipulator (fig. 10). Considering the last proposed mechanism (fig. 9), we have replaced the hydraulic cylinder with a worm-gear transmission (1+2) at which the gear 2 is fixed to the bar 2 that moves the whole system, the worm 1 being actuated by an electrical motor ME.

## 6. MODELING AND SIMULATION OF THE LIFTING MANIPULATOR

Nowadays, by means of advanced CAD software systems, any component or mechanical assembly having a complex structure can be modeled and simulated. Designing a virtual entity, with precisely 3D dimensions (using three-dimensional space), requires a spatial vision and a detail-orientated eye. In order to simulate a process, we need that part to be as much as possible like the real one. So, a virtual material with real properties can be applied to it. Thus, we can obtain a component which has its own characteristics that can be updated anytime. The parametrical design has the advantage that by modifying a geometrical parameter of the component, all the other dimensions will be automatically changed in correlation with the given constraints.

Further, certain virtual assemblies, obtained by connecting their mobile mechanical elements, can be created, accomplishing mechanisms with one or more mobilities that can be animated and simulated on their operation as if they would have a real behavior.

Let's consider the mono-mobile lifting manipulator with improved efficiency depicted in figure 9. The first step is the modeling of the main mechanical components such as the base 0 (truck body), the hydraulic cylinders 1

(including the pistons 2) as actuators, the T-rockers 3 linked to cylinder's pistons, the rods 4 fixed to the transversal shaft (that connects the two parallel lifting mechanisms and sustains the two waste bins by special supports), the rockers 5, and the waste bins 6 (including their lids 7).

All these components of the lifting manipulator have been modeled by using a 2D sketcher. Then, the third dimension for each element, by using the 3D module, was created. Many other commands were used in order to shape the right configuration of them. The total number of parts (subcomponents) is 24!

Afterwards, these parts were assembled using a specific virtual workbench by adding the connection elements (such as shafts, pins and bearings) between them that, in fact, represent the rotate joints (fig. 11). The only sliding joints are between pistons and cylinders.

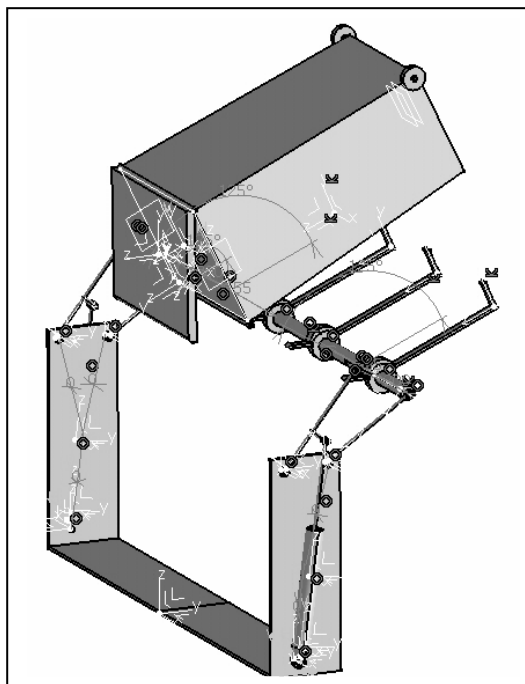


Fig. 11. CAD modeling and kinematical simulation of the mono-mobile lifting manipulator with improved efficiency

It is necessary to be mentioned that before assembling the components, the accuracy of each part dimension has to be checked, so that the outcome should be a perfect combined product. The 3D rendering of the lifting manipulator assembly can be achieved very easy just by computer mouse. The system can be rotated, moved or zoomed in/out by user in order to see the final product from any point of view.

For the kinematical joint applying between the mechanism's components, the manipulator mobility has to be considered. This lifting mechanism having 1 DOF, the sliding range of the driving cylinders can be imposed so that the manipulator working space to be modeled, related to the necessity of a completely waste unloading from the bins.

Two simply solutions on lifting manipulators have been proposed. One of them is meant to reduce the waste truck consumption by implementing a high efficiency mechanism. The other is to reduce the city pollution by using an electric powered driving transmission. The first one has been CAD modeled and simulated in order to test its kinematical performances.

## REFERENCES

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- [3]\*\*\*[www.tigerdude.com/garbage](http://www.tigerdude.com/garbage); [www.mechlift.com](http://www.mechlift.com) .