ANALYSIS AND DESIGN OF JOBS FOR CONTROL OF CUMULATIVE TRAUMA DISORDERS: PLASTIC FORKS/SPOONS PACKING JOB

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ABSTRACT

Cumulative trauma disorders caused by repetitive hand and arm movements were studied in this paper for a plastic forks/spoons packing job. The job was categorised into several work elements associated with the trunk, hand and arm motions. The number of motions were then counted for each eight-hour shift. It was found that the worker has to move the right hand 45,211 times and left hand 45,931 times for a working shift. In some of the motions, the worker has to twist the trunk. This relatively high number of motions is due to the current positioning of equipment and tools. With some considerations on the positioning and orientation such as distances and heights, the repetitive motions of the hands and arms can be significantly reduced, hence minimising the risk factors associated with cumulative trauma disorders.

Keywords : *Cumulative Trauma Disorder, Ergonomic, Risk Factor*

1. INTRODUCTION

This ergonomic job analysis is based on a typical factory layout for injection moulding and packing of plastic forks and spoons. The present investigation is a structured approach for identifying risk factors associated with overexertion injuries and disorders. The job analysis survey was confined to injection moulding of styrene (plastic) section involved in plastic forks and spoons.

Many risk factors could occur on more than one element, for example, repetitive motions, awkward postures, temperature extremes, etc. The results of an ergonomic evaluation or risk factors associated with each specific work element of plastic forks/spoons packing job were separately analysed.

2. JOB DESCRIPTION

The job in this study is plastic forks and spoons packing in the injection moulding department. Working on any injection moulding assembly line, the ergonomic stresses do not usually differ from hour to hour, or even day to day. A total of 9 out of 11 injection moulding machines were in operation at the time of survey, and each machine required only one worker. A particular worker at Machine #I4 (see Figure 1) was studied and interviewed. She has been on the same job for 17 months.

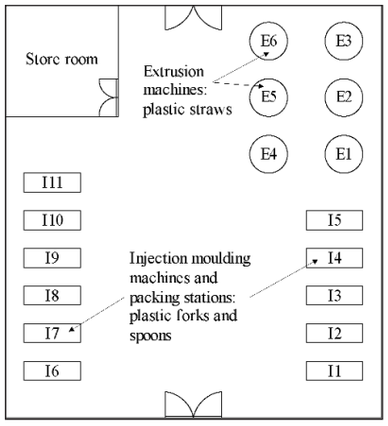
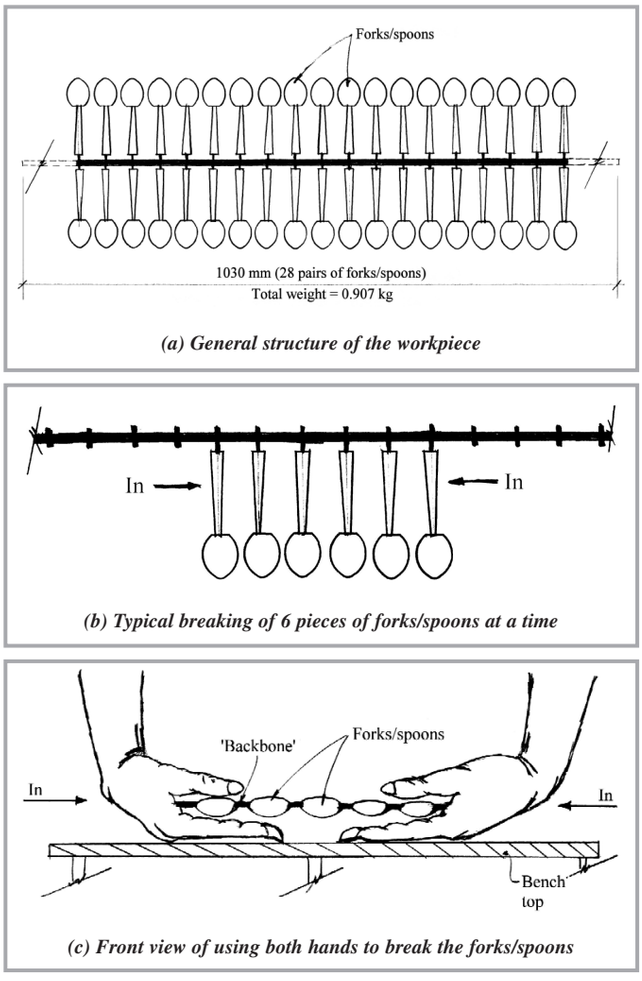


Figure 1: General layout plan of a single storey plastic injection moulding and extrusion plant

After the injection moulding process, the 'packer' at the packing station has to use both hands to break up 5 to 8 forks/spoons at a time (see Figure 2) attached to the 'backbone' [see Figure 2(a)]. After that, the



(a) General structure of the workpiece

(b) Typical breaking of 6 pieces of forks/spoons at a time

(c) Front view of using both hands to break the forks/spoons

Figure 2: Workpiece and the typical way of breaking up the forks/spoons

'packer' needs to pack them into the shipping case, weighs out the required weight, and puts the carton on the shipping conveyor belt (see Figure 3). Defective forks/spoons and unwanted 'backbones' are thrown into the overhead pelletiser for recycling.

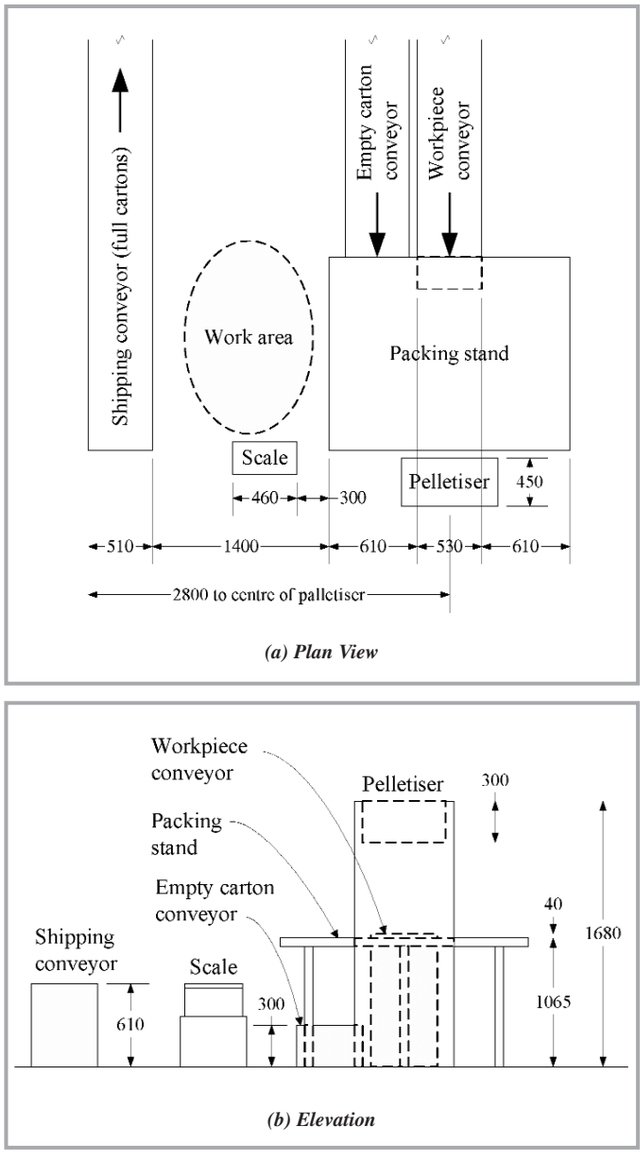


Figure 3: Plastic forks/spoons packing station (dimensions in mm)

The injection moulding and packing section works on three shifts. The time of analysis was on the third shift, which starts at 11:00 pm and ends at 7:00 am. During the shift, there are two 10-minute breaks, at 12:45 am and 4:30 am, and a 25-minute break at 2:45 am. In addition, the worker is given 10 minutes at the end of the shift to clean up the workstation. The actual work time on this job is (480 – 25 – 20 – 10) = 425 minutes or 7.25 hours.

In the forks/spoons packing job described above, the standard time allowed to break, pack and weigh to specific weight of one carton of forks/spoons of approximately 300 pieces is 0.59 minute (35.40 seconds). If the work schedule and work pace are strictly followed, the worker performs this job for 425 minutes in one shift. Within this time, approximately 720 cartons will be packed. There are approximately 300 forks/spoons per carton, so a total of 300 x 720 = 216,000 forks or spoons are packed in each shift.

Based on the quality control data, it was found that 4% of the products (forks/spoons) are rejected, resulting in 4/100 x 216,000 = 8,640 forks/spoons = 8, 640/300 = 29 cartons. In addition, attachment space between forks/spoons on the 'backbone' is about 40 mm apart. Thus there are approximately 40 x (29 + 720) x 300 = 8,988,000 mm = 8,988 m of 'backbone(s)' and 8,640 forks/spoons need to be forced/thrown into the pelletiser.

The worker in the study breaks up 6 forks/spoons at a time and the number of repetitive motions (both arms above shoulders) during a normal shift is calculated to be (29 + 720) x 300/6 = 37,450 times.

The job rotation schedule and associated trunk postures on this plastic forks/spoons packing job were calculated or sampled and summarised in Table 1. The non-neutral trunk posture as indicated in Table 1 refers to the posture where the worker has to bend the trunk. The whole list of tools and parts associated with the plastic forks/spoons packing operation is summarised in Table 2.

Each ergonomic problem identified during this job analysis associated with a specific activity is broken down into 5 basic elements of regular and irregular elements as shown in Table 3. Regular elements are typically performed on each unit (a carton of 300 forks/spoons) or production. Irregular elements are cleaning up workstation and sweeping the station floor.

The detailed work method analysis of the plastic forks/spoons packing job is presented in Table 3. For this analysis, the unit of production is considered to be one carton of 300 plastic (polystyrene) forks/spoons.

3. ANALYSIS AND DISCUSSION

3.1. RISK FACTORS ASSOCIATED WITH SPECIFIC WORK ELEMENTS

3.1.1. Element 1: Get Empty Carton and Place on Packing Stand

The conveyor belt (300 mm above floor) delivers the empty cartons on the left of the worker weighing 0.75 kg each as shown in Figure 3. Force should not pose any significant risk factor on this element. As shown in Figure 4, the extremely low position of the empty carton (300 mm above floor) requires the worker to bend and twist the trunk in order to grasp it. It is calculated, during a normal working day, the worker has to repeat this 720 times. This awkward posture is strongly associated with increased risk of lower back pain (back injury). Other generic risk factors like exposures to vibration (not applicable) and extreme temperatures (73 ºF) while performing this element are considered insignificant.

3.1.2. Element 2a: Reach to the Workpiece and Pull it on Bench in Position with Left Hand

This element involves the pulling of workpiece weighing 0.907 kg for an approximate distance of 1 m. The task is relatively light; force should not be considered a significant risk factor. However, the worker has to lean forward, bend and /or twist the trunk in order to grasp it and pull it to the right quickly. During a normal day, this element is repeated 5.4 x (720 + 29) = 4,045 times (frequency of 5.4 as shown in Table 3 for 749 units of production), which greatly poses the danger of increased risk of back injury.

Table 1: Job rotation schedule and associated trunk postures on a plastic forks/spoons packing job

Activities	Duration (min)	Faction of time in non-neutral trunk posture	Duration in non-neutral trunk posture
Regular element			
1. Bend down for empty carton and put on top of bench	14.40	0.030	12.96
2. Reject 29 cartons	26.58	0.055	21.00
3. Pelletising 'backbones'	46.81	0.096	42.00
4. Scaling and put on shipping conveyor	24.00	0.050	24.00
5. Both arms above shoulder	313.21	0.653	157.00
6. Break	45.00	0.092	--
Irregular Element			
7. Cleaning workstation and sweeping floor	10.00	0.020	--

Table 2: Equipment tools and parts associated with the plastic forks/spoons packing

Items	Weight or required force (kg)
Equipment and tools	
1. Empty carton conveyor	NA
2. Full carton conveyor	NA
3. Packing stand	NA
4. Plastic forks/spoons conveyor	NA
5. Gloves	NA
6. Pelletizer	NA
7. Scale/weighing machine	NA
Parts handled	
8. Plastic forks	Negligible
9. Plastic spoons	Negligible
10. Empty carton	0.75
11. Full carton	3.50
12. 'Backbones'	Negligible

Table 3: Work method analysis for the plastic forks/spoons packing job (1 cycle = 1 carton of 300 forks/spoons)

Description	Left Hand	Right Hand	Freq/Cycle
Regular element			
1. Get empty carton and place on packing stand	✓	✓	1
2a. Reach to the workpiece and pull it on bench in position	✓		5.4
2b. Pull the workpiece to position		✓	5.4
3a. Break up 6 forks/spoons at a time and place them in the carton	✓	✓	50
3b. If necessary, discard defective forks/spoons in RH		✓	1
3c. If necessary, discard defective forks/spoons in LH	✓		1
3d. Discard the 'backbones' in RH		✓	3
3e. Discard the 'backbones' in LH	✓		3
4a. When carton is full, transfer onto scale by both hands (see Figure 3)	✓	✓	1
4b. Transfer full carton from scale to shipping conveyor (see Figure 3)	✓	✓	1
Irregular Element			
5. Cleaning workstation and sweeping floor	✓	✓	1

3.1.3. Element 2b: Pull the Workpiece to Position with Right Hand

Workpiece is considered to be negligibly light, and the trunk is in natural position. Exposures to any generic risk factors while performing this element are not considered significant.

3.1.4. Element 3a: Break up 6 Forks/Spoons at a Time and Place Them in the Carton

Breaking up forks/spoons as in Figure 2 requires relatively extremely low force. However, the associated repetitiveness of the same motion, and the required posture to place the plastic forks/spoons in the carton in an orderly manner are of great concern [2]. During a normal shift, the worker has to repeat the motions [see Figures 2(b) and (c)] by 50 x (720 + 29) = 37,450 times (frequency of 50 as shown in Table 3 for 749 units of production). The posture required for this activity involves extreme palm forward flexion of the wrist [see Figure 2(c)].

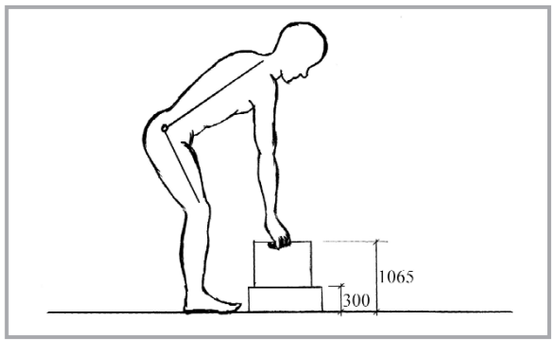


Figure 4: Posture of a worker bending the trunk when reaching down to grasp an empty carton (dimensions in mm)

In the meantime, the 6 plastic forks/spoons being broken up at a time are held in the palms and transferred into the carton by both hands through a height of at least 350 mm above bench level. Again, the motion is repeated 37,450 times during a normal shift. The loading activity requires a posture of forward flexion of the shoulders, and both arms are to be above shoulder height. The required arm and shoulder postures may increase the shoulder disorder, while the required wrist postures may increase the risk of wrist and hand disorders. The risk factors are extensively aggravated by the highly repetitive nature of the element.

Without taking into consideration the posture and low force applied, a careful analysis of this extreme repetitive magnitude of approximately 37,450 times per shift can be a sole factor in the development of upper extremely cumulative trauma disorders [3]. Exposures to other generic risk factors while performing this element are considered insignificant.

3.1.5. Elements 3b and 3d: If Necessary, Discard Defective Forks/Spoons in Right Hand and/or Discard the 'Backbones' in Right Hand

The pelletiser is located at the right side of the worker, 750 mm from the worker and 1600 mm above floor level. Elements 3b and 3d share the same

posture which involve forward lean of body, forward flexion of the right shoulders, and ulnar deviation of palm.

During a normal shift, the elements are repeated 749 x (1 + 3) = 2,996 times (frequencies of 1 for Element 3b and 3 for Element 3d respectively as shown in Table 3 for 749 units of production). The highly repetitive nature and awkward posture are associated with increase risk of back injury and development of upper extremity cumulative trauma disorders [3]. However, the risk of wrist and hand disorders should not be considered significant since relatively light materials are handled.

3.1.6. Elements 3c and 3e: If Necessary, Discard Defective Forks/Spoons in Left Hand and/or Discard the 'Backbones' in Left Hand

Elements 3c and 3e and associated repetitive motion, risk factors are the same as in elements 3b and 3d discussed above. But, when dealing with left hand, the worker not only has to lean forward more, and more forward flexion of left shoulder, but also has to twist his/her trunk in order to reach the feed-hole pelletiser. The overall effect is assumed to be the same, but more severe as compared to elements 3b and 3d.

Table 4: Work Practices Guide Analysis - lifting a full carton

Criterion	Measured Value	NIOSH Factor (ACGIH 1983)
Horizontal Location Factor (HF)	H = 1955 mm	0.20
Vertical Location Factor (VF)	V = 1065 mm	0.88
Vertical Distance (DF)	D = 455 mm	0.87
Frequency Factor (FF)	1.70/min	0.86

Table 5: Number of hand motions for each work element

	Left Hand	Right Hand
Element 1	720	0
Elements 2a and 2b	4,045	4,045
Element 3a	37,450	37,450
Element 3b	0	749
Element 3c	749	0
Element 3d	0	2,247
Element 3e	2,247	0
Elements 4a and 4b	720	720
Total	45,931	45,211

3.1.7. Elements 4a and 4b: When Carton is Full, Transfer onto Scale by Both Hands and Transfer Full Carton from Scale to Shipping Conveyor

The weight of a full case of plastic forks/spoons is approximately 3.5 kg. However, with reference to NIOSH Work Practices Guide for Manual Lifting [1] of quantitative procedure for evaluating the risk associated with this type of activities shows an acceptable lift of 5.27 kg as presented in Table 4. The NIOSH Work Practices Guide [1]assumes that lifting is performed in the sagittal plane with no twisting. Due to the positions of the conveyors, scale and pelletising machine, some twisting are bound to occur during these activities.

The computed acceptable lift of 5.27 kg is sufficiently high and force should not be a problem in this element. However, the worker needs to twist his/her trunk while transferring the carton. As implied, awkward posture could increase the risk of back injury.

This element is performed 720 times per shift. The NIOSH Work Practices Guide [1] considers the effects of repetitive lifting.

3.1.8. Element 5: Cleaning Workstation and Sweeping Floor

This activity does not pose any significant risk factors, since it is judged to have little exertion, negligible awkward posture or wrist twisting.

3.2. GENERAL RISK FACTORS ASSOCIATED WITH THE TOTAL JOB

In this analysis, both left and right hands are extensively involved. Summarised in Table 5 is a straightforward computation in determining total number of trunk, left and right hand exertions for a worker working in one shift.

The sequence of work elements in this job involves extremely high repetitive use of both upper extremities. However, right hand exertions are calculated to be 720 times fewer than left hand. This is attributed to the fact that in element 1 (picking up the empty carton), right hand remains idle.

4. CONTROLLING EXPOSURES OR RECOMMENDATIONS TO GENERIC RISK FACTORS

The risk factors associated with each of the work element in a shift have been discussed in the previous section. Each of this work element can be improved to avoid the risk factor associated with it. The preceding discussion describes the recommendation to improve the working environment in order to prevent the risk factors.

4.1. ELEMENT 1: GET EMPTY CARTON AND PLACE ON PACKING STAND

The height of the empty carton conveyor must be elevated to the same level as the work bench [4]. Otherwise, there should be another worker there to put the empty cartons on the work bench instead of using the conveyor belt.

4.2. ELEMENTS 2A AND 2B: REACH TO THE WORKPIECE WITH LEFT HAND AND PULL IT ON BENCH IN POSITION WITH LEFT OR RIGHT HAND

The workpiece should run right through the middle of the working table so that the worker does not have to bend forward greatly to pull the workpiece onto the bench and in position. Furthermore, the position of the workpiece and empty carton conveyors should be interchanged, so the number of "bend forward" motions will be reduced from 4,045 to 720 repetitions per shift.

4.3. ELEMENT 3A: BREAK UP 6 FORKS/ SPOONS AT A TIME AND PLACE THEM IN THE CARTON

The height of the work bench should be redesigned so that the elbows are kept below midtorso height [4]. The design could be based upon statistics from the US Department of Health, Education, and Welfare National Health Survey; women in the 5th percentile are 1.511 m tall and men in the 95th percentile are 1.869 m tall. Otherwise, height adjustable work benches can be used [4].

In addition, mechanical aid to separate the forks/spoons from the 'backbones' on the way to the work benches can be introduced. Then, the work left to be carried out is to pick up the forks/spoons and palletise the 'backbones'.

4.4. ELEMENTS 3B, 3C, 3D AND 3E: IF NECESSARY, DISCARD DEFECTIVE FORKS/SPOONS IN LEFT OR RIGHT HAND AND/OR DISCARD THE 'BACKBONES' IN LEFT OR RIGHT HAND

The feed position of the pelletiser should be greatly lowered to the same level of work bench, so the worker can simply 'sweep-in' the unwanted 'backbones' or rejected forks/spoons. Centralisation of the palletising system, that is, adding a conveyor belt on the right side of the work bench (few centimetres lower than the bench), also help in reducing the arm motions. What the worker has to do is to sweep the unwanted materials to the right and be carried to the central pelletiser.

4.5. ELEMENTS 4A AND 4B: WHEN CARTON IS FULL, TRANSFER ONTO SCALE, THEN ONTO SHIPPING CONVEYOR BY BOTH HANDS

Firstly, the scale system needs to be improved. A particular 'slot' need to be opened either on left or right of the bench, and the scale should be placed right under the opening (100 to 125 mm lower than the bench surface). What the worker needs to do is to 'slot-in' the empty carton on top of the scale.

Secondly, the scale display or the weight indicator should be elevated (be adjustable), and placed in the opposite end of or facing the worker. This eliminates the motion of bending down to take the reading.

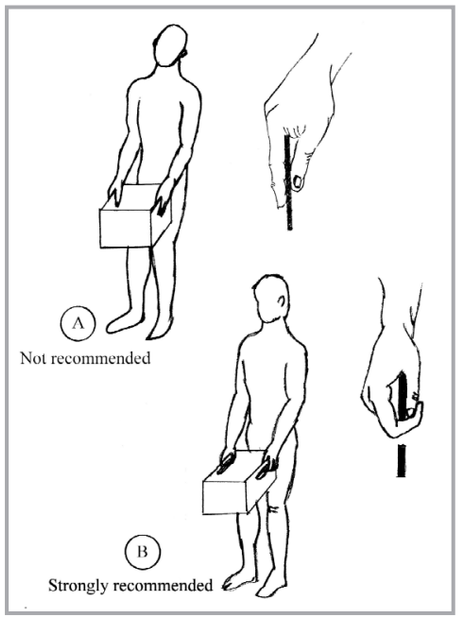


Figure 5: Recommended improvement to carton handling where three to four times as much muscle force is required to hold a carton by pinching (A) as in a power grip (B)

Thirdly, an L-shaped shipping conveyor belt can be designed, which is an extension of the existing shipping conveyor to the right of the worker/work bench. In this way, the worker does not have to twist the trunk. Instead, he just needs to push/pull the full carton to the shipping conveyor on his right.

Fourthly, some kind of rollers should be installed between the short distance of the 'slot' and shipping conveyor to reduce the push/pull force required.

Lastly, handle openings could be introduced on the cartons so that the worker can hold using power grip posture as shown in Figure 5.

5. CONCLUSIONS

The job of packing plastic forks/spoons was analysed for the hand and arm motions. The study was carried out in a normal shift of 8 hours at a typical work station. It was found that the actual working time in this job is 7.25 hours, packing a total number of 216,000 forks/spoons.

The job was categorised into 5 basic work elements for the analysis of hand and trunk motions. A detail analysis showed that the total hand motions are 45,931 times for the left hand, and 45,211 for the right hand. The left hand has to move 720 times more than the right hand in lifting and pulling the empty cartons in place. In some of these hand motions, the worker needs to twist the trunk in an awkward posture.

Some of these hand motions including trunk twisting may lead to risk factors associated with cumulative trauma disorders. However, some improvements are possible by a little consideration of placement and position of tools and equipments as follows:

(a) The height of the empty carton conveyor can be elevated to the work bench level.
(b) The workpiece conveyor should be positioned to run right through the middle of the working table so that the worker does not have to bend forward greatly to pull the workpiece in place. A good solution is by interchanging the workpiece and empty carton conveyors.
(c) The height of the work bench should be redesigned so that the elbows are kept below midtorso height.
(d) The feed position of the pelletiser should be greatly lowered to the same level of work bench so that the worker can simply 'sweep-in' the unwanted 'backbones' or rejected forks/spoons.
(e) Some minor improvements on slot and display on the scale and the shipping conveyor may help in reducing the trunk twisting.
(f) Use handle openings on the cartons so that the worker can hold using power grip posture. ■

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