

Performance Comparison between Conventional and Flexible Box Erecting Machines Using Dispatching Rules

Min Kyu Kim, Eun Young Lee, Dong Woo Son, Yoon Seok Chang

Abstract—In this paper, we introduce a flexible box erecting machine (BEM) that swiftly and automatically transforms cardboard into a three dimensional box. Recently, the parcel service and home-shopping industries have grown rapidly, and there is an increasing need for various box types to ship various products. However, workers cannot fold thousands of boxes manually in a day. As such, automatic BEMs are garnering greater attention. This study takes equipment operation into consideration as well as mechanical improvements in order to design a BEM that is able to outperform its conventional counterparts. We analyzed six dispatching rules – First In First Out (FIFO), Shortest Processing Time (SPT), Earliest Due Date (EDD), Setup Avoidance, EDD + SPT, and EDD + Setup Avoidance – to determine which one was most suitable for BEM operation. Consequently, SPT and Setup Avoidance were found to be the most critical rules, followed by EDD + Setup Avoidance, EDD + SPT, EDD, and FIFO. This hierarchy was valid for both our conventional BEM and our new flexible BEM from the viewpoint of processing time. We believe that this research can contribute to flexible BEM management, which has the potential to increase productivity and convenience.

Keywords—Automation, box erecting machine, dispatching rule, setup time.

I. INTRODUCTION

A lot of companies produce small quantity batches to meet the immediate needs of their consumers. This flexibility enables companies to grow in e-business areas like social commerce where various small products need to be handled. This circumstance requires a higher level of flexibility with respect to box erecting machines (BEMs), which are required to swiftly transform cardboard into three-dimensional boxes of various sizes. In particular, as growth has occurred in the parcel express service and home shopping industries, the utilization rate of box packaging equipment has also increased.

BEMs are generally integrated into a company's operations when boxes need to be erected more quickly so as to overcome finite limitations in terms of resources, space, and the number of employees. BEMs usually use corrugated cardboard. Current technology regarding conventional BEMs has focused on

erecting boxes of the same size, so if an urgent request occurs, new boxes have to be made manually. Moreover, when operating a conventional BEM, a worker must manually adjust components to accommodate different box sizes. In addition, conventional BEMs cannot operate until all adjustments are completed. This creates further delays, lowers productivity, and increases manpower requirements.

In order to improve performance and operation, this study analyzed the weaknesses inherent to conventional BEMs in detail. Two companies – Company C and Company O – were visited, each of which was equipped with a conventional BEM. Their work cycles consisted of setting the components, moving boxes to the machine, lifting a device for putting the boxes in place, arranging the boxes, adjusting a support device, removing box straps, and disposing of straps. We categorized the factors that needed improvement, as shown in Table I.

TABLE I
FACTORS NEEDING IMPROVEMENT IN CONVENTIONAL BEMs

Main Factors	Current Issues
Low Flexibility	If different box types are needed urgently during a cycle, workers have to move previously placed boxes and introduce new boxes.
	When various box types are needed, workers must take preliminary measures to follow the correct procedures and stack the boxes already made. The setup operation time is significantly affected by a worker's skill-level.
Manual Setup Operation	For setting a box erecting machine, there are 5 parts to set. So the task is beyond ability of 1 worker.
	Motion of setting the machine is physically demanding. It is difficult for smaller or less muscular workers to set without aid. Moreover, workers complain of arm and waist pains.
	If a worker makes a mistake setting up the numerical values, it can cause machine errors.



Fig. 1 A conventional box erecting machine

We focused on two main factors – the low flexibility and the

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need for manual setup – that were prevalent when using a conventional BEM. This is depicted in Fig. 1. These factors were then reflected on so as to lead to the development of a flexible BEM.

It was deemed important to design a flexible BEM that could automatically make various box types in a single machine, as opposed to conventional BEMs that are limited in that they only work with same-sized boxes. Accordingly, the necessary research was initiated via the Development of Smart Material Handling Machine Project (2013 – 2016) funded by the Korean Ministry of Land Infrastructure and Transport. This research involved collaboration between Korea Aerospace University and a small business called Jae-Pack [1].

II. FLEXIBLE BOX ERECTING MACHINE

The weaknesses of conventional BEMs were studied in order to develop a flexible BEM that could accommodate various box types and take advantage of an automatic setup. This led to the design of a flexible BEM with a box supplying cart, modular magazines, a conveyor, a turning queue zone, and an erecting zone, as depicted in Fig. 2.

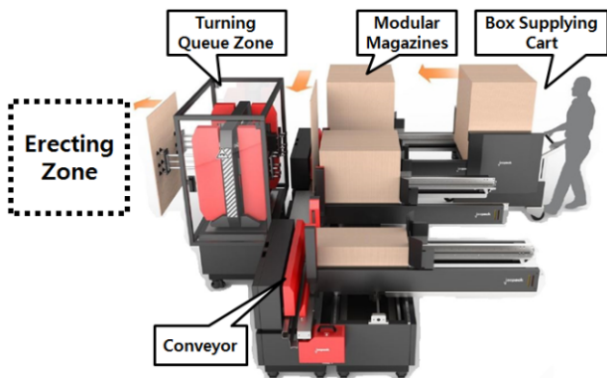


Fig. 2 A flexible box erecting machine

Basically, three magazines are utilized in the box supply section of the BEM to achieve flexibility. This eliminates the time needed to remove previously added boxes in order to replace them with a new box type. In addition, the magazines are designed to be modular, as seen in Fig. 3. This allows the number of magazines to be adjusted according to the required characteristics. This modular structure is able to improve the maintenance convenience when a box push device or magazine breaks down.



Fig. 3 Modular magazine

With conventional BEMs, erecting and adjusting magazine modules is conducted manually, and it is difficult for workers to accurately adjust the width of a magazine to fit the box width. The flexible BEM is able to overcome this drawback via an automatic setup system that connects five components associated with setup changes. This makes it more convenient in terms of achieving box type flexibility. The automatic system does away with the need to turn handles manually. Because setup operations generally account for more than 50% of the overall operation time, the automatic capabilities of the flexible BEM significantly decrease cycle times. To summarize, the flexible BEM, which includes detachable magazines, boasts greater adjustment accuracy and speed as a result of replacing the manual adjustment device with an automatic mode to change box types.

III. RELEVANT LITERATURE REVIEW

There is a significant amount of research related to automation equipment such as automatic picking systems. However, studies on BEMs are not abundant. Only a few studies have been conducted on BEMs or packaging technologies. Reference [2] concentrated on previous secondary packaging line delays in a transfusion bag production line. To overcome this problem, they analyzed procedural factors (i.e. procedure type, time, number of workers, working intensity, and product quality) and proposed a new packaging line layout, including a BEM. Reference [3] focused on productivity improvements for a packaging machine in a manual production line. They analyzed the operation balance rate using the MODular Arrangement of Predetermined Time Standard (MODAPTS). Reference [4] introduced a field application for a case packing robot. This robot was a new high-speed pick-and-place parallel robot with three translational degrees of freedom. Meanwhile, dispatching rules have been studied in various industries. In addition, there are many simulation studies applying a variety of rules related to dispatching rules.

Reference [5] described a mixed dispatching rule (MDR), which enabled the mixing of two or more dispatching rules for all machines. Reference [6] defined four different flexibility levels and analyzed the effects of dispatching rules on the scheduling performance. Reference [7] introduced a field application for dispatching rules in capital goods companies and suggested that the best dispatching rule depends on the particular circumstances.

With BEMs and packaging technologies, operations scheduling is important, as is the improvement of hardware to achieve greater efficiency by enhancing setup operations. However, to the best of the authors' knowledge, no research has yet been conducted on dispatching rules for BEMs or packaging lines. As such, focus was placed on the relevant research on dispatching rules in order to derive the optimal operation method for a flexible BEM. Subsequently, a simulation was conducted.

IV. SIMULATION OF DISPATCHING RULES

Obviously, performance improves when flexibility is achieved through a change from a manual setup structure to an automatic setup system. Nevertheless, a simulation was conducted to determine the extent of the performance increase achieved by the flexible BEM over the conventional BEM with respect to order scheduling methods. In short, the first objective of the simulation was a productivity comparison between a conventional BEM with under 10 minutes setup time and a flexible BEM with a setup time under 10 seconds. The second objective was to determine which dispatching rule suited the flexible BEM with respect to optimizing performance.

There are many dispatching rules, but four of them were selected and applied to the BEM, as shown in Table II.

TABLE II
DISPATCHING RULES

	Description
FIFO (First In First Out)	A method for organizing and manipulating a data buffer, where the oldest (first) entry, or 'head' of the queue, is processed first [8]
SPT (Shortest Processing Time)	A method that uses the process with the shortest processing time until completion is selected to execute
EDD (Earliest Due Date)	A method for organizing and manipulating a data buffer, where the order with an earlier due date is processed first
Setup Avoidance	A method for organizing and manipulation a data buffer to minimize the total setup time
EDD + SPT	A method using SPT based on EDD
EDD + Setup Avoidance	A method for minimizing the total setup time based on EDD

Table III serves as an example of an order sheet in which the dispatching rules are easy to understand.

TABLE III
AN EXAMPLE ORDER SHEET

Order No	Box Size	Number of Boxes to Be Erected	Due Date
1	Big	30	6
2	Small	75	18
3	Medium	25	18
4	Big	40	6
5	Big	20	12
6	Medium	15	18
7	Small	10	12
8	Small	60	6
9	Medium	35	18
10	Medium	70	6

First, according to FIFO, the operation should be processed in numerical order (i.e., 1 2 3 4 5 6 7 8 9 10) because the first order is processed first.

Second, according to SPT, the operation should use the following order: 2 7 8 3 6 9 10 1 4 5. This is because erecting boxes in order from small to medium to big achieves the shortest setup time. Accordingly, the boxes were categorized as small, medium, and big, and they were processed in that order.

Third, according to EDD, the operation should use the following order: 1 4 8 10 5 7 2 3 6 9. This is because the earlier due date is processed first. Accordingly, the boxes were

categorized according to 6-minute, 12-minute, and 18-minute due dates, and they were processed in that order.

Fourth, according to Setup Avoidance, the operation should use the following order: 2 7 8 3 6 9 10 1 4 5. This order is the same as that of the SPT because the purpose of Setup Avoidance is to minimize the number of setup operations and the total setup time.

Fifth, according to EDD + SPT, the operation should use the following order: 8 10 1 4 7 5 2 3 6 9. This is because the EDD rule was first used to determine the categorization, and then the SPT rule was applied based on the EDD rule.

Sixth, according to EDD + Setup Avoidance, the operation should use the following order: 8 10 1 4 5 7 2 3 6 9. This is because the EDD rule was first used to determine the categorization, and then the Setup Avoidance rule was applied based on the EDD rule.

A. Simulation Design

A simulation was conducted using C# tool and split up into two scenarios with six cases to analyze. Scenario 1 used a conventional BEM for orders processed according to FIFO, SPT, EDD, Setup Avoidance, EDD + SPT, and EDD + Setup Avoidance. Scenario 2 used a flexible BEM for orders processed according to FIFO, SPT, EDD, Setup Avoidance, EDD + SPT, and EDD + Setup Avoidance.

The following points were assumed. First, it was assumed that a sufficient number of boxes was loaded into their magazines (i.e., box replenishment was not needed). Second, the process of erecting boxes was assumed to have lasted from the moment the box was discharged to the moment at which the machine finished taping the bottom of the box. Third, the number of boxes that could be ordered was assumed to be 250, and the box sizes were assumed to exist in equal numbers for each order that occurred consistently. Fourth, it was assumed that there three box types. A was the small box, B was the medium box, and C was the big box. Fifth, the setup time was assumed to include the time needed to supply boxes. Finally, it was assumed that errors did not occur when boxes were erected, and that the erecting speeds and setup times differed according to box size. These assumptions are shown in detail in Table IV for each scenario.

TABLE IV
SIMULATION ASSUMPTIONS

	Scenario 1	Scenario 2
Number of boxes per order	10 or 20 or 30 or 40 or 50 randomly	
Erecting speed	A : 0.04min / box	
	B : 0.045min / box	
	C : 0.05min / box	
Setup time	Under 10 minutes	Under 10 seconds
Speed of conveyor	-	1.8 m/s
Number of orders	250 orders per day	

For Scenario 2, the magazine for the B boxes was attached between the magazines for the A and C boxes, as depicted in Fig. 2. Therefore, the A and C boxes were moved to the queue zone. The B boxes, on the other hand, did not need to move. As such, the boxes were divided according to A, C, and B.

B. Results Analysis

The results are shown in Tables V and VI. First, when comparing the flexible and conventional BEMs according to FIFO, the flexible BEM reduced the time necessary to erect boxes from 1523.27 to 344.70 minutes (i.e., 23% of the original time was needed), and it achieved a due date success rate of 0.74. Second, according to SPT, the total time needed to erect boxes was reduced from 351.68 to 338.40 minutes (i.e., 96 % of the original time was needed), and the flexible BEM achieved a due date success rate of 0.76. Third, according to EDD, the total time needed to erect boxes was reduced from 1489.53 to 344.54 minutes (i.e., 23% of the original time was needed), and the flexible BEM achieved a due date success rate of 1.00. Fourth, according to Setup Avoidance, the total time needed to erect boxes was reduced from 351.68 to 338.40 minutes (i.e., 96% of the original time was needed), and the flexible BEM achieved a due date success rate of 0.76. Fifth, according to EDD + SPT, the total time needed to erect boxes decreased from 524.16 to 339.82 minutes (i.e., 65% of the original time was needed), and the flexible BEM achieved a due date success rate of 1.00. Sixth, according to EDD + Setup Avoidance, the total time needed to erect boxes was reduced from 458.99 to 339.44 minutes (i.e., 74% of the original time was needed), and the flexible BEM achieved a due date success rate of 1.00. In addition, in order sheet, absolute box erecting time does not change regardless of order sequence with all dispatching rules. However, total processing time including setup time is the shortest when boxes are processed as the following order: small, medium, and big box. In case of applying SPT rules boxes are erected (i.e. assembled) as the following order: small, medium, and big box. That is the reason why the simulation results of SPT and Setup Avoidance are exactly the same. When applying Setup Avoidance, the order with the same type of box is processed first so as to minimize the number of setup operation. Thus, the order with SPT and Setup Avoidance is processed with same sequence, which leads to same result. However, the simulation results of EDD + SPT and EDD + Setup Avoidance are different. In case of EDD + SPT, order sequence is repeated using the following order: small, medium, and big box based on due-date (e.g., small, medium, big, small, medium, and big box). On the contrary, in case of EDD + Setup Avoidance, order sequence is considering the number of setup operation based on due-date (e.g., small, medium, big, big, medium, and small box).

TABLE V
SIMULATION RESULTS (SCENARIO 1)

Scenario 1		
	Processing Time (minutes)	Due date success rate
FIFO	1523.27	0.20
SPT	351.68	0.75
EDD	1489.53	0.04
Setup Avoidance	351.68	0.75
EDD + SPT	524.16	0.98
EDD + Setup Avoidance	458.99	1.00

The analysis results indicated that the flexible BEM was

more effective than the conventional BEM from the perspective of the time needed to erect boxes. Regarding the conventional BEM, the setup time was significantly longer, using a scale of 'under 10 minutes' rather than 'under 10 seconds' for the flexible BEM. Thus, the number of boxes erected was significantly different. The flexible BEM's setup time was 30 seconds, as stated in the R&D plan. However, the actual setup time can be expected to be completed in under 10 seconds, so the effectiveness gap between the flexible and conventional BEM will actually be wider as seen from simulation results. Also, it is revealed that SPT and Setup Avoidance achieved the shortest processing time. In cases of flexible BEM with EDD, EDD + SPT, and EDD + Setup Avoidance, due-date can be met as well as less processing time.

TABLE VI
SIMULATION RESULTS (SCENARIO 2)

Scenario 2		
	Processing Time (minutes)	Due date success rate
FIFO	344.70	0.74
SPT	338.40	0.76
EDD	344.54	1.00
Setup Avoidance	338.40	0.76
EDD + SPT	339.82	1.00
EDD + Setup Avoidance	339.44	1.00

V.CONCLUSION

In this paper, the weaknesses of conventional BEMs were studied in order to develop a flexible BEM that would be able to overcome these weaknesses. Two main factors were drawn from the case studies of conventional BEMs – low flexibility and manual setup operations. Accordingly, research was carried out on how these drawbacks could be overcome, and this research was applied to the development of a flexible BEM. Likewise, research was conducted on various dispatching rules in order to improve the operation of the flexible BEM. The subsequent improvements would complement the improvements in hardware. As a result, six dispatching rule methods – FIFO, SPT, EDD, Setup Avoidance, EDD + SPT, EDD + Setup Avoidance – were selected for the flexible BEM.

The simulation results for the comparison between the flexible and conventional BEMs indicated that the flexible BEM was able to achieve a maximum 4.5 times reduction in box erecting time. Moreover, if the actual feasible setup time of the flexible BEM is considered, difference will significantly increase. Also, SPT and Setup Avoidance were found to be the most critical rules which have the shortest processing time. But EDD + Setup Avoidance is recommended in consideration of due-date.

It is expected that the flexible BEM can be used in warehouses where various box types are required. It is evident that this flexible BEM would be able to help operators work more efficiently and comfortably.

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