

The Role of Packaging Automation in Improving Operational Efficiency, Productivity, and Manufacturing Performance in Corrugated Packaging Operations

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Abstract

This study focuses on the impact of packaging automation on operational efficiency, productivity and manufacturing performance of corrugated packaging. Secondary literature based analysis is used to critique evidence related to the: case handling, cardboard feeding, palletizing and quality control areas, and integrated packaging lines. It could be found that the application of automation can reduce the number of labors, optimize the process, participate in quality control, enhance the productivity of the packaging process, with the compatibility of the equipment and packaging characteristics and production requirements. However, the benefit will be different, depending on inter-system integration, capacity balancing, reliability and context of use. The study stresses the investigation of packaging automation in terms of system level performance and not on individual machine efficiencies.

Keywords: *Packaging Automation, Corrugated Packaging, Operational Efficiency, Productivity, Palletizing, Manufacturing Performance.*

I. INTRODUCTION

Background

Corrugated packaging serves a vital role in product handling, material flow, distribution and also storage, as well as in manufacturing. Packaging operations assist to contain product and also impact labor, throughput, product flow and downstream logistics [1]. Physical procedures of packaging can be streamlined through packaging automation, involving case packers, case erectors, sealers, tapers, conveying systems and integrated packaging lines, offering consistent and efficient manufacturing procedures and supporting enhanced productivity.

Problem Statement

Manual or not well integrated corrugated packaging procedures can lead to production bottlenecks, inability to manage uniform production rate, packaging variability, repetitive demands of labor needed, downtime, and loss of capacity. Installation of automation does not assure improved operational performance [2]. For optimal effectiveness, packaging design, product attributes, production volume, line

demands, equipment specifications and operating conditions need to be incorporated to deliver adequate improvements in efficiency, productivity and also manufacturing outcomes throughout.

Research Gap

Current literature analyzes packaging machines or a single operation of an individual machine or application of packaging automation, while packaging automation as an operating system is not sufficiently analyzed. More awareness also needs to be shared about roles of corrugated packaging specifications in selection and incorporation of automation [3]. Greater understanding is required regarding the impact of integrated equipment on process performance and the influence of relationships between them and overall packaging effectiveness in terms of operational efficiency, productivity, quality, capacity utilization and manufacturing effectiveness.

Research Aim and Objectives

Research Aim

The purpose of the study is to investigate the role of packaging automation on operational efficiency, productivity and manufacturing performance of the corrugated packaging operations with process consistency, throughput, capacity utilization and operational effectiveness.

Research Objectives

- *To evaluate explores automation impacting efficiency throughout corrugated packaging operations and processes.*
- *To verify correlation between automated packaging equipment, throughput, capacity utilization, productivity and process inaccuracy.*
- *Search and identify factors affecting successful packaging operating automation selection, integration & implementation.*
- *To determine the effect of integrated packaging automation on the quality, cost, productivity and overall manufacturing performance.*

Research Contributions

The study delivers a covered package's automation integration correlated with operational as well as

manufacturing results offering an integrated insight for utilizing packaged products. Interactions between automation, throughput, productivity, process consistency, capacity utilization, quality and cost improvement are explored. It also offers practical details of the levers for efficiencies and effectiveness of the packaging system in advanced production centers.

II. RELATED WORK

Role of Automation in Improving Efficiency Across Corrugated Packaging Operations and Processes

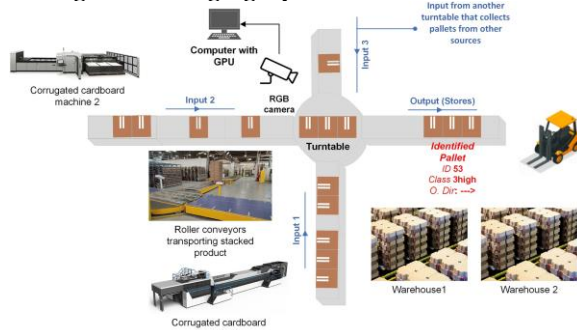


Fig 1. Role of Packaging Automation in Improving Corrugated Packaging Process Efficiency

Automation offers opportunities to enhance efficiencies in corrugated packaging through removing repetitive handling of corrugates, streamlining manufacturing flows, and linking together continuous packaging of corrugates [4]. However, benefits in terms of efficiency can follow while identification of 'bottlenecks' which are going to be improved through automation is where gains can come from rather than simply replacing manual procedures [5]. Uncoordinated equipment can cause constraints to be transferred elsewhere in the line [6]. Hence, the utilization of automation needs to be assessed considering various aspects of overall cycle time, process flow, labor usage, equipment coordination and reliability within packaging production procedure [7].

Automated Packaging Equipment for Enhancing Throughput, Capacity Utilization, Productivity, and Process Consistency

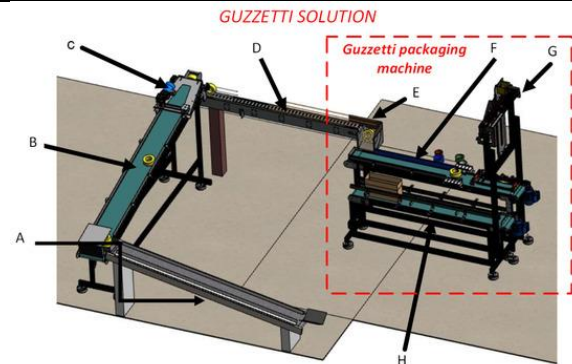


Fig 2. Influence of Automated Packaging Equipment on Throughput, Capacity Utilization, Productivity, and Process Consistency

Automated case erectors/packers/ sealers/ conveyors and palletizers can improve the packaging speed and lower the level of variation in manual repetitive operations [8]. However, upstream and downstream capacity is limited, gains in equipment speed cannot result in higher system productivity [9]. Overall performance of equipment needs to be evaluated based on a combination of the utilization, throughput, consistency and productive capacity [10]. There needs to be a balance between the capabilities of the individual lines, that do not result in under-use, congestion, or introduce new inefficiencies [11].

Operational Factors Influencing Packaging Automation Selection, Integration, Implementation, and System Effectiveness

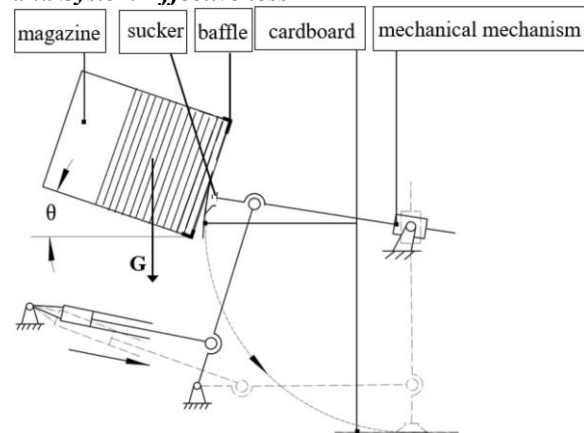


Fig 3. Operational Factors Influencing Packaging Automation Selection, Integration, and Implementation Effectiveness

Technologically appropriate equipment is not the only part of packaging automation that is successful [12]. Implementation effectiveness is affected by dimensions and features of the packaging involved; product features and production volumes; required throughputs; available floor space; equipment

compatibility; required maintenance and also workforce capabilities [13]. Not taking operational conditions into account can lead to integration challenges and the benefits can be diminished [14]. Therefore, equipment selection for any automation needs to be based on actual procedure and equipment integration needs to be done such that the equipment is reliable enough to operate in the larger corrugated packaging system that it serves [15].

Integrated Packaging Automation for Quality, Cost Efficiency, Productivity, and Manufacturing Performance Improvement

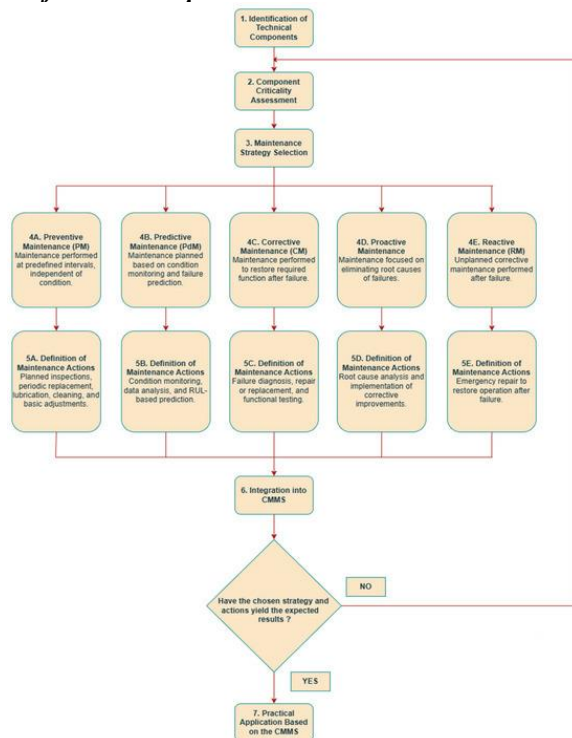


Fig 4. Integrated Packaging Automation and Its Impact on Quality, Cost Efficiency, Productivity, and Manufacturing Performance

Packaging automation can help manufacturers with enhanced manufacturing performance through assuring quality packaging, minimizing human involvement, boosting productivity and optimizing the usage of resources [16]. There can be added expenses with equipment, maintenance, training, and also incorporation of automation that can be difficult to offset savings [17]. Assessing for quality, operating costs, productivity, reliability and flexibility, and efficiency of overall procedure offers a more balanced approach to decision making while packaging automation adds lasting improvements in manufacturing [18].

Literature gap

Literature focused on packaging automation from a technological or equipment-specific point of view, lacking insights into linkages of operational impacts [19]. There is a lack of knowledge characterizing the interaction between requirements for corrugated packaging, choice of automation systems, incorporation of equipment and performance of the packaging procedure [20]. In order to consider the role that automation can play in improving an organization's more encompassing efficiency, productivity, quality and manufacturing performance, reflection on relationships is required.

III. CONCEPTUAL FRAMEWORK

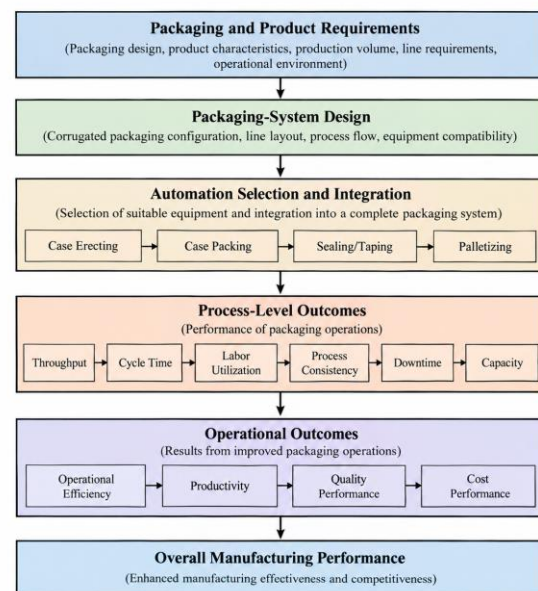


Fig 5. Conceptual Framework Linking Corrugated Packaging Requirements, Packaging Automation, and Manufacturing Performance

Conceptual framework illustrates how the use of packaging automation in turn can impact and affect operational and manufacturing performance in a series of interconnected phases [21]. Packaging-system design needs to be based on packaging and product specifications, followed by selection and incorporation of an appropriate level of automation [30]. Depending on the level of automation, procedures involved in packaging cases can be integrated, case packing, coordinated processes containing case erecting, sealing/taping and palletizing [22]. The impact of adequate integration can be on the process level in terms of cycle time, throughput, labor utilization, process consistency, downtime along with production capacity. Changes in measures can impact on operational efficiency as well as productivity, quality along with cost performance and in overall manufacturing performance. The system

needs not to be automated for optimum results [23]. Effectiveness depends on equipment suitability, equipment compatibility with corrugated packaging and products, production needs, integration throughout the packaging procedure, equipment maintenance, and process management. Hence, packaging automation is seen as an operational system of automation by which improvement of manufacturing procedure is dependent on the extent of automation and also on alignment of requirements, implementation, capacity along with situations of operation.

IV. RESEARCH METHODOLOGY

Research Design

Analytical research design is secondary research and also literature based which aims to investigate packaging automation in corrugate packaging operation [24]. Current academic and industry research is carefully studied to understand the relationship among automation and operational efficiency, productivity, process consistency and manufacturing performance.

Secondary Data Sources

Secondary evidence comes from conference papers, peer-reviewed journal articles, institutional publications or industrial papers along with technical studies published in various scholarly databases [28]. Evidence base provided by sources covers packaging technologies, operational practices, implementation of automation within the packaging line, or manufacturing-performance outcomes [25]. Research analysis does not involve personal employment data, nor data from specific workplaces.

Source Selection Criteria

Sources are carefully chosen to be credible, relevant, recent, and also applicable to the topics of corrugated packaging and corrugated automation [29]. Publications can be given priority while published since 2020 on following topics relating to case erecting, case packing, sealing, palletizing, throughput, productivity, quality, costs or capacity/operational efficiency [26]. Sources can be repeated with established conceptual or technical foundations at an earlier time point.

Secondary Analysis Approach

The four research objectives are utilized as a framework for critical evaluation and incorporation of evidence. The relation between the analytical number is:

$$MP = f(PR, AI, PO, OO)$$

MP is manufacturing performance; PR is packaging requirements; AI is integration with automation; PO is the outcomes of the process; and OO the operational outcomes. Productivity can also be evaluated as:

$$Productivity = \frac{Output}{Resource\ Input}$$

Equations are to support the reported secondary evidence while not original quantitative modelling.

Reliability and Research Limitations

Reliability is reinforced while evidence is compared to sources that are credible. Direct generalization of information is limited, however, due to the variability in equipment configurations, production quantity and volume, measures of performance, and industries and operating environments [27]. As a result, values of automation gained from a particular packaging operation are not assumed to be the same from another.

V. RESULT AND ANALYSIS

Secondary evidence is analyzed in relation to the four research objectives. Numerical figures provided by referenced studies are not results of calculations that are not clearly marked. Therefore, findings are not in the context of primary experimentation, but of secondary analysis.

Automation and Efficiency in Corrugated Packaging Operations

Level of automation can change utilization of labor resources without significantly reducing cycle time of work stations [1]. Two operators were needed in the investigated packaging operation and after introduction of an automatic tape-packaging machine, only one operator was needed. On the other hand, while operating under automation, the cycle time is reported to have increased from 19 s to 23 s. In this study's results, lab results show that evaluating a machine's efficiency based on speed alone is not enough; labor efficiency and compatibility with surrounding production stages need to also be taken into account to calculate overall efficiency of machines.

In [1] the secondary value of labor reduction is evaluated as

$$LR = \frac{N_m - N_a}{N_m} \times 100 = \frac{2 - 1}{2} \times 100 = 50\%$$

and N_a is the number of operators required while operating automatically, while N_m is for manual operation. The particular cycle-time change is:

$$CTC = \frac{CT_a - CT_m}{CT_m} \times 100 = \frac{23 - 19}{19} \times 100 = 21.05\%$$

Manual and automated packaging-station cycle time

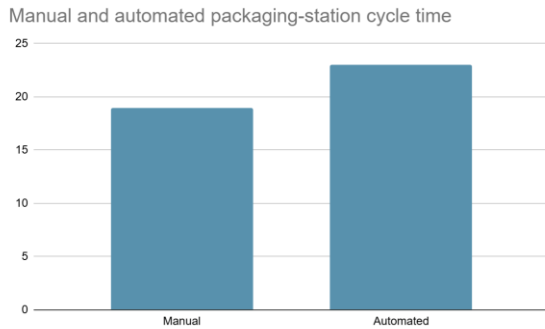


Fig 6. Manual and Automated Packaging-Station Cycle Time

Therefore, the chart cannot be taken as proof that automation leads to a faster production process. Through automation cycle time locally increased by 21.05%, while direct staffing was cut by 50%.

Packaging Equipment, Throughput, Capacity, Productivity, and Consistency

A different evaluation of automated palletizing in combination with quality inspecting is given [2]. A system has been reported that reports processing and inspection of 21 boxes in 11.53 min. Converting published duration to

$$t = (11 \times 60) + 33 = 693 \text{ s.}$$

Processing rate is corresponding to,

$$PR = \frac{21}{693} \times 60 = 1.82 \text{ boxes/min.}$$

An average processing time is

$$APT = \frac{693}{21} = 33.0 \text{ s./box}$$

System utilized a robot to self-configure pallets, and was concurrently utilized for packaging defect inspection, taping, label inspection, weight inspection, etc. [2]. Hence, it is more than about throughput as activities like handling and quality control are also seen as operational contributions.

Automated palletizing processing indicators

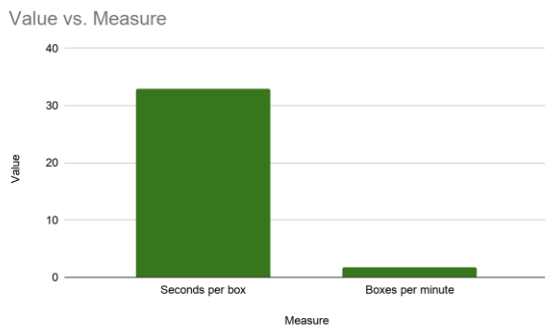


Fig 7. Calculated performance indicators from 21 boxes processed in 693 seconds

The figure represents two similar time-based performance metrics (33.0 s/box as well as 1.82

boxes/min) instead of utilizing three on a single numerical axis to accommodate the different units of values, since the above number (693) represents a large number of seconds.

Factors Affecting Automation Selection, Integration, and Implementation

Secondary evidence also indicates that behavior of packaging material affects reliability for automation. The investigation has concluded that the baffle height, back pressure, inclination of the magazine and the coefficient of friction between the cardboard sheets are important factors that influenced automatic vacuum picking [3]. Experimental picking was repeated 10 times for each condition tested. The study results showed that the baffle height has been reduced below 25 mm, the ratio of picking out increased, while disorder and multiple feeds also increased a little. If baffle height was above 25 mm picking out was very low and damage was high [3].

In the same study, dynamic friction is tested at values of 0.2, 0.4, 0.6 and 0.8, it is found that increasing the friction generated lower picking-out, higher friction generated greater disorder or multiple feeding [3]. The results are relevant to the corrugated packaging automation field where Case feeding and forming is dependent upon physical interaction between the packaging material and handling machinery.

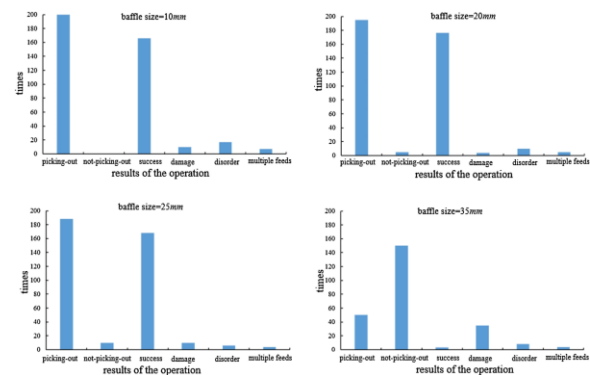


Fig 8. Operating Parameters Affecting Automatic Cardboard Picking

This figure presents the various baffle heights tested of 10, 20, 25, and 35 mm in the form of a categorical operating condition. It should not however give imaginary success percentages since only directional data can provide a percentage for each of the available data categories when it is presented numerically in text reports.

Integrated Automation and Manufacturing Performance

The broader evidence suggests that the effectiveness of automation is linked to the integration of packaging phases. As argued in [4], the individual machines are

coordinated in the overall line and the modular investigation of the packaging-line presented in this paper illustrates this. In [5] the industry investigation of packaging-machinery pertained to the following three packaging-machine companies, and it also investigated the automation-architecture conditions specific to the packaging industry. Conceptual representation of a combined evidence can be

$$MP = f(T, L, Q, R, I),$$

Where MP is manufacturing performance, T is the throughput, L is the labor utilization, Q is the quality, R denotes reliability, and I denotes integration effectiveness. These above-mentioned equations organize relationships, which have been discovered based on the secondary evidence and it is not a primary statistical model.

TABLE 1. SECONDARY EVIDENCE ON PACKAGING AUTOMATION AND OPERATIONAL PERFORMANCE

Automation Area	Secondary Evidence	Reported Benefit	Limitation/Trade-off	Performance Implication
Automated tape packaging	Operators 2 → 1	Reducing 50% in direct operator requirement	Cycle time increased 19 → 23 s (21.05%)	Labor utilization can enhance in spite of a slower localize cycle [1].
Automated palletizing and QC	21 boxes in 693 s	Quality inspection and Palletizing combined within one operation [2].	Performance relies on configuration of application-specific system	≈1.82 boxes/min and 33.0 s/box
Automatic cardboard picking	200 repetitions/ tested condition	Adjusting Operating parameters helps to support dependent automatic feeding	Performance is sensitive to equipment settings and board behavior [3].	Packaging material and feeding equipment require appropriate alignment
Automatic cardboard picking	Friction coefficients 0.2, 0.4, 0.6, 0.8 evaluated	Lower friction enhanced picking-out performance values [3].	Lower friction may increase multiple feeding or disorder	Material properties can influence feeding consistency and downstream reliability
Modular packaging line	Interconnected coordinated automation modules	Supporting coordinated operation among various packaging steps	Requires compatible communication and component interfaces	Promotes line-level rather than isolated-machine automation [4].
Packaging machinery integration	Three packaging-machine companies are the evidence	Supporting automation architectures that supports the operational needs [5].	Configuration depends on company-specific conditions and process.	Contextual equipment integration supports system-level performance

Secondary results show overall that packaging automation must be considered as a whole operation

system. Even better performance in manufacturing does not always follow with faster equipment.

Combined, all of these factors determine the feasibility of obtaining sustainable operational benefit from automation.

VI. DISCUSSION AND IMPLICATIONS

Interpretation of Findings

The secondary findings prove that packaging automation is considered as an entire chain of operations and cannot be viewed based on the individual machine performance measurements. Lower labor demand, along with lower material handling and quality checks in one operation can be achieved by combining automated palletizing with handling and quality checking. Thus, the efficiency of automation relies on the need for balancing throughput, material properties, future-friendliness, the compatibility of equipment and line coordination.

Operational Implications

In packaging applications, automation decisions are based on production volumes, corrugated material properties, desired throughput, available equipment capacity, equipment interfaces and maintenance practices. The data show that the increased speed of processors can lead to reintroduction of bottlenecks into other processors. Managers should therefore consider the entire packaging flow and be sure to maintain a level balance of case handling, sealing, conveying and palletizing capacity.

Manufacturing Performance Implications

For productivity, production quality, labor efficiency and manufacturing reliability, integrated packaging automation helps to realize two requirements such as matching equipment capabilities with operational requirements. However higher levels of automation don't necessarily make for better performance. Optimizing sustainable manufacturing performance in packaging operations, the decisions about investment must take into account the realization costs, labor needs, maintenance, flexibility and possible suboptimal utilization of the investment.

VII. CONCLUSION AND FUTURE DIRECTIONS

Conclusion

The findings of this study indicate that the right packaging pattern coupled with the appropriate production methods can improve operational efficiency, productivity, quality and manufacturing performance of packaging, as automated packaging comes to pass. The results from the secondary evidence indicate that benefits critically rely on: equipment compatibility, material characteristics, integration of process and balance of capacity. As such, the effort in automation cannot only be done by looking at one single machine's performance.

Future Directions

Future research is needed using in-depth case studies of corrugated packaging plants before and after packaging automation and other comparisons of plant operations pre and post automation, and longitudinal studies, are warranted. More research is needed to assess equipment utilization, return on investment, maintenance, adaptation of the workforce, sustainability of the packaging materials, and compatibility of the packaging material. Comparing the performance of integrated case erecting, packing, sealing, conveying and palletizing systems could produce a clearer sign of long-term manufacturing performance and scalability.

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