Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 3	Month	: June
p-ISSN	: 1693-5462	Volume	: 21	Year	: 2023

Article Processing Dates: Received on 2023-01-05, Reviewed on 2023-01-21, Revised on 2023-01-25, Accepted on 2023-01-27, and Available online on 2023-06-30

Experimental and discrete event simulation (DES) modeling analysis of the belt conveyor conveying capacity

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Abstract

Belt conveyors can continuously move the desired amount of material from one location to another. The conveying capacity of the conveyor must be met based on the previous design criteria. The belt conveyor must operate at the appropriate conveying speed and queue time interval. Higher or lower conveyor speeds and queue time intervals can cause a decrease in efficiency and productivity. The objectives of this study are 1) to determine the effect of the independent variables (observations), namely, the speed of the head pully conveyor and the time interval of the box queue, on the conveyor performance, 2) to obtain information on the normality profile and significance of the conveyor performance data. This research is oriented toward experimental and quantitative research designs. The independent variables observed are the speed of the head pully belt conveyor and the box queuing time interval on the dependent variable, namely the belt conveyor conveying capacity. The data collection technique is in the form of direct measurements on the conveyor system and the collection of output data from the previously designed DES modeling. Two types of analysis used are comparative quantitative analysis methods and statistical-based analysis. The results showed a significant influence between the independent variables of speed and box queue time interval on the conveying capacity of the belt conveyor. Another result is that the conveyor capacity data obtained from this study have a near-normal distribution and a high significance level.

Keywords: belt conveyor, conveying capacity, speed, queue time, discrete event simulation

1 Introduction

Belt conveyors are a form of technology and automation that companies widely use. One of the main benefits of belt conveyors is that they can help improve efficiency and productivity by automating the movement of materials. It can save time and labor compared to manually moving materials from one location to another.

A belt conveyor is a material handling equipment that uses a continuous belt to move goods from one location to another, whether the material is bulk, packaged, or other individual products [1], [2]. It is often used in manufacturing and distribution environments to move materials such as raw materials, finished products, and packaging between different areas of a facility.

Manufacturing and distribution arrangements using belt conveyors that are not designed for efficiency and productivity will result in increased energy consumption and costs [3], reduced conveying capacity [4], increased production downtime, and reduced product quality [5]. When designing or operating a belt conveyor, it is important to consider the trade-offs between belt speed, queue time, and conveying capacity so that material transfer is proportional. The optimum balance will depend on the specific needs and constraints of the company and the material being conveyed.

Referring to the above phenomenon that the conveying capacity of belt conveyors is an important factor in the planning and operation of conveying systems, experimental analysis, and DES modeling are problem-solving solutions that can help to determine the optimum capacity.

Therefore, this research is very important because it can provide value or benefits in several aspects, such as understanding concepts or theories, the potential to provide solutions or answers to problems faced by society or industry, and technological development or innovation.

This research was preceded by a review of the studies that we consider the most relevant. The review of previous studies that are most relevant to this research refers to the criteria of similarity in several aspects: the theme of "belt conveyor," one or more variables observed, the methods used, and the research results. These criteria can be used together or in part.

There has been much research on belt conveyors. Okwudibe *et al.* [6] have designed and tested a prototype conveyor belt for agricultural consumption. The methods used in his research are designing, manufacturing, and testing conveyor belts. The results obtained showed that the conveyor can move without slippage. J. Li *et al.* [7] have conducted a modeling study of the conveyor belt system by treating vibration damping, dynamic stress, conveying capacity, and conveyor belt speed. The results show that the "modeling" approach can improve the accuracy of the dynamic design of belt conveyors.

Feng *et al.* [8] studied conveyor belts used in the mining industry. His research uses mathematical modeling and continuous dynamics methods using acceleration and load distribution variables. His research showed that the dynamic model of the conveyor belt was created and solved correctly. A. Beg *et al.* [9] conducted an experimental study by making a prototype conveyor belt. The research variables are speed variation, the mass of the conveyor belt carrying the load, and the variation of distance between 2 shaft axes. His research found the maximum mass that can be conveyed on his belt conveyor prototype. Vishnu Datta *et al.* [10] conducted an experimental study by making a belt conveyor prototype. The research variables are speed variation and load capacity variation. The results of his research showed that the process of handling 6,500 grams of material has stability within 9 to 10 minutes.

Muas *et al.* [11] conducted a design study and data analysis on the conveyor belt in the gravel crushing industry. The research variables are belt workload, idler spacing, belt inclination, and drive motor power. The results of his research indicate that the results of designing a conveyor belt with different observation variables can be used in the industry. F. Zeng *et al.* [1] have carried out research based on experimental comparisons and dynamic modeling. The research variables are speed variables and material flow fluctuations. The results showed that the proposed model could be used to optimize the operating procedures of the belt conveyor system. M. Bajda *et al.* [3] conducted a study by building a test rig for industrial use. The research variable is the indentation rolling resistance of the belt. The results showed that replacing standard belts with reconditioned belts resulted in a

4.8% increase in power consumption, while using energy-efficient belts resulted in a 15.3% decrease. H. Qiu *et al*. [4] conducted a study by modeling (finite element method) the mechanism of a roller belt conveyor. The research variables were stress distribution and deformation of the roller conveyor. The results showed that the roller structure was suitable, and the strength and rigidity of the roller met the design requirements. D. He *et al*. [12] have studied designing a conveyor belt energy model or building a variable speed drive control algorithm. The research variables are variable speed and variable acceleration. The results ensure the healthy transient operation and improve speed control application by considering potential risks and conveyor dynamics.

D. He *et al*. [13] have studied simulation models using Delft system modeling and Estimation-Calculation-Optimisation (ECO). The research variable is the speed variable for energy savings. The simulation results show that during eight hours of operation, active speed control can achieve hourly average energy savings of 16.21% compared to the constant speed operation scenario. J. Shen *et al.* [14] conducted experimental and modeling studies using FEM and DEM. The variables studied were velocity and belt tension. The simulation results showed good agreement with the experimental measurements, indicating the validation of the coupled FEM and DEM models.

In addition, several research studies have used discrete event simulation (DES) modeling. E. Yilmaz *et al*. [15] conducted a modeling study of a conveyor belt used as a conveying action tool for coal mining. The research methodology used was modeling and analysis of the longwall mining system with DES. The research variables are operational data related to the coal-cutting process. This study recommends a framework for data collection, analysis, and interpretation of operational data to evaluate conveyor belt performance. J. Greberg *et al*. [16] conducted case studies on different types of trucks to analyze conceptual conveying methods using DES. The research variables were truck capacity, loading time, unloading time, empty speed, and average loaded speed. The results show that DES is suitable for investigating and analyzing mine operations before making investments or implementing new systems.

S. Grigolato *et al*. [17] carried out a study to evaluate table and stringer board production for wooden pallet production using DES. The study variables were timber diameter and productive layout against actual production rates. The simulation results showed that the main gains could be obtained by improving the layout and identifying the cross-cut saw as the main bottleneck in the production line. S. Que *et al*. [18] also carried out a study using a simulation-based optimization approach to improve the efficiency of the oil sand's continuous conveying system at the operational level. The research variables were bucket process parameters (such as bucket tipping, return, and loading time). The results recommended that the GAP transfer system operates with a 70-tonne shovel.

The previous findings have provided an important basis for the development of this research. However, it still needs analysis and investigating the differences in context: The method or algorithm is simpler yet accurate compared to previous studies; The data used is more recent, or the data is from a different source than previous studies; the analysis of the conveying capacity of belt conveyors under different operating conditions or the analysis of the capacity with different variables; The recommendations provided are centered on improving the operating efficiency; The application of the research results is centered on different industries, or the application is on a different scale.

The context of the novelty of this research is that it can be the basis for the development of a monitoring system, particularly for conveying capacity, which can detect potential problems in the belt conveyor conveying system before they occur. Furthermore, this research can be the basis for developing new methods to improve the operational efficiency of belt conveyor conveying systems.

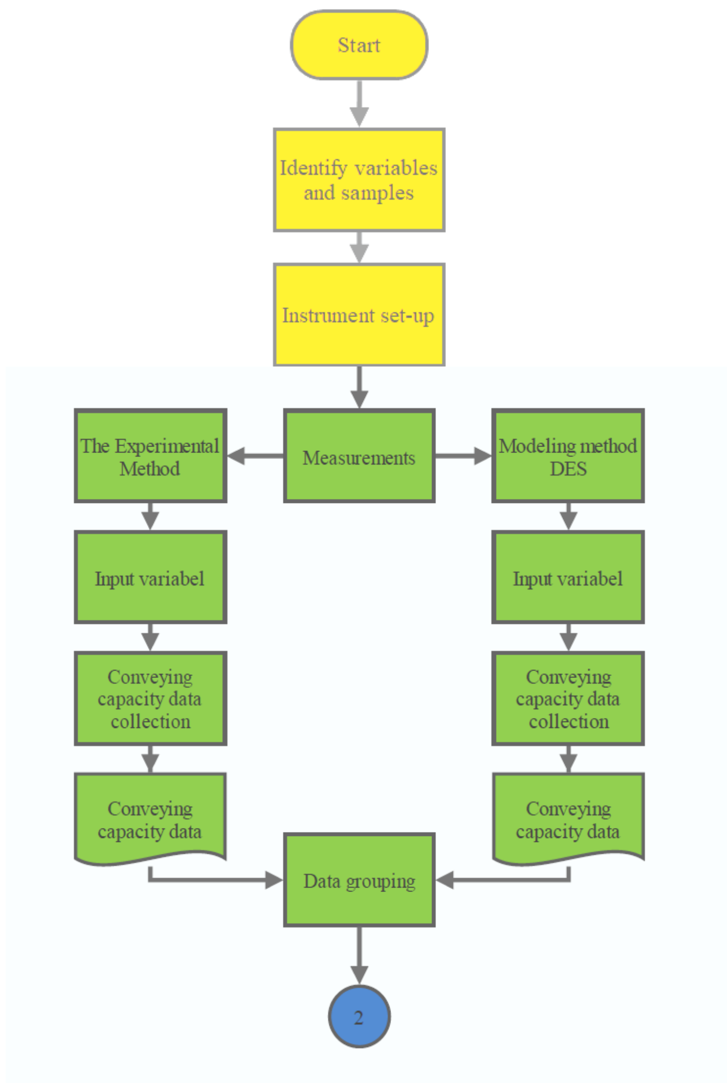
Based on the above description, the research objectives to analyze the effect of the independent variables (observations), namely the speed of the head pully belt conveyor and the time interval of the box queue on the belt conveyor conveying capacity, and to obtain information on the normality profile and the significance of the belt conveyor conveying capacity data. The significance of the data will be known through the H0 hypothesis test: The difference in treatment (experimental analysis and DES modeling) does not have a significant effect on the conveyor conveying capacity or H1: The difference in treatment (experimental analysis and DES modeling) has a significant effect on the conveyor conveying capacity.

2 Research Methods

2.1 Research Flow Chart

In general, the research activities are divided into five groups. Group 1, identifies the variables to be observed. Group 2, preparing instruments (belt conveyor system equipment, Arduino uno application, and flexsim 2021 application). Group 3, measuring, collecting, and classifying data. Group 4, analyze (comparative quantitative analysis and statistical analysis). Group 5, concludes and makes recommendations.

The process or steps of the research are shown in the research flow chart, as shown in Fig. 1.



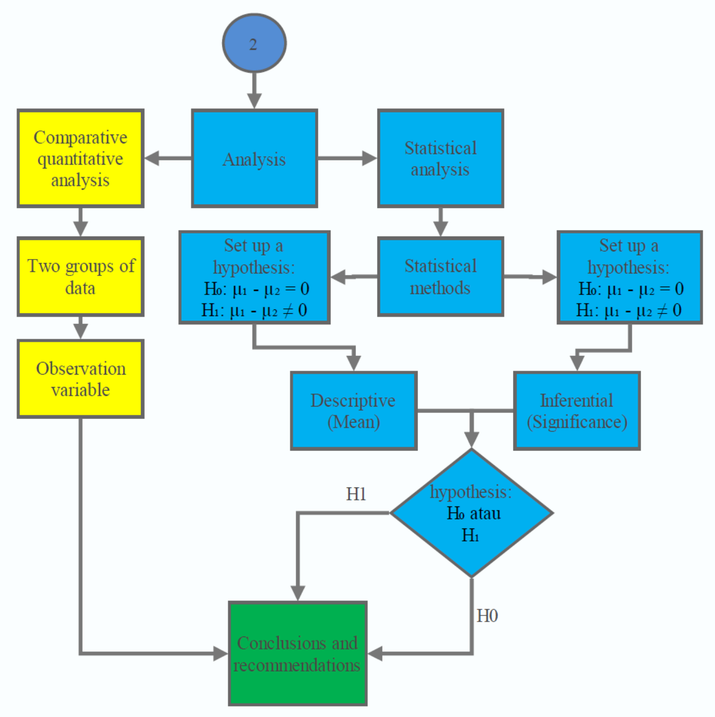


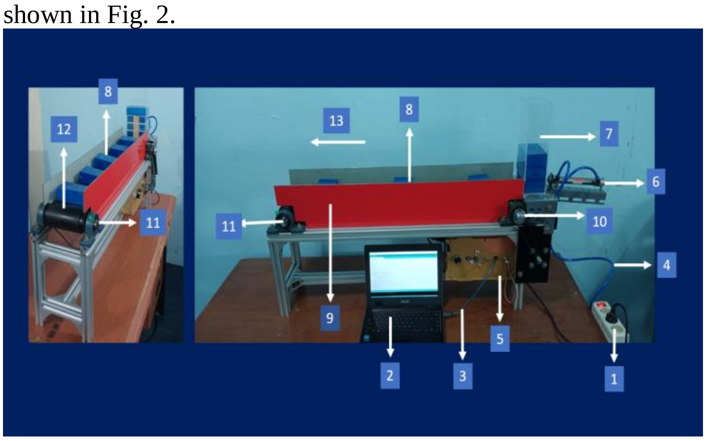
Fig. 1. Flow chart for research

2.2 Variables Studied

Two independent variables were studied (observed) in this research, namely the speed of the stepper motor and the time interval for the cylinder rod to push the box. The Arduino uno application controls both variables. The variations of the stepper motor speed are 10, 20, and 30 rpm. At the same time, the variation of the time interval for the cylinder rod to push the box is 5, 7, and 9 seconds. The two independent variables are combined with different variations to get the dependent variable, "conveying capacity."

2.3 Test Setup

The setup prior to measuring conveyor conveying capacity is shown in Fig. 2.



1. power supply; 2. laptop; 3. USB cable; 4. pneumatic hose; 5. electrical panel box; 6. pneumatic cylinder; 7. box storage bin; 8. delivered box; 9. partition wall; 10. head pully; 11. tail pully; 12. flat belt; 13. The direction of box movement

Fig. 2. Belt conveyor equipment assembly

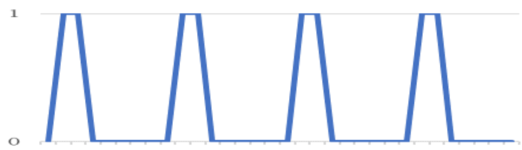
Referring to Fig. 2, it can be explained that when the motor is switched on, it will cause the head pulley and conveyor belt to move. The pneumatic rod cylinder pushes the bottom box stored in the queue to enter the conveyor. The cylinder then returns to its original position. At a certain time interval, the rod cylinder again pushes the bottom case to enter the conveyor. Meanwhile, the box above the conveyor moves toward the output side of the trajectory.

The function of each of the components in the assembly of the conveyor belt equipment is given in Table 1.

Table 1. Component functions in the assembly

Components	Component functions
Power supply	Provides electrical power to run the belt conveyor system.
Laptop + Arduino uno app.	To control the speed of the head pully and the stroke interval of the pneumatic cylinder.
USB cable	To connect data from the laptop to the electrical installation panel box.
Pneumatic hose	To connect the airflow from the compressor to the pneumatic cylinder.
Electrical panel box	To process the "processor" data sourced from the Arduino uno application to the relevant parts of the system.
Pneumatic cylinder	To push the box.
Bin the storage box	As a storage box.
Box	As an object delivered or conveyed.
Partition wall	To prevent the box from leaving the track and to guide the box out of the conveyor.
Head pully	To drive a conveyor belt.
Tail pully	To provide belt tension and a place to turn the conveyor belt.
Flat belt	To deliver the box from the input side to the output side.
Delivery direction	To indicate the direction of box movement.

The position displacement diagram of the pneumatic cylinder (actuator) when pushing the box is shown in Fig. 3.



0: initial position of the cylinder (idle); 1: final position of the cylinder (forward or push box)

Fig. 3. The plot of pneumatic actuator position displacement (y-axis) versus box queue time interval (x-axis)

Some of the key conveyor data used to measure box conveying capacity are shown in Table 2.

Table 2. Conveyor belt physical data

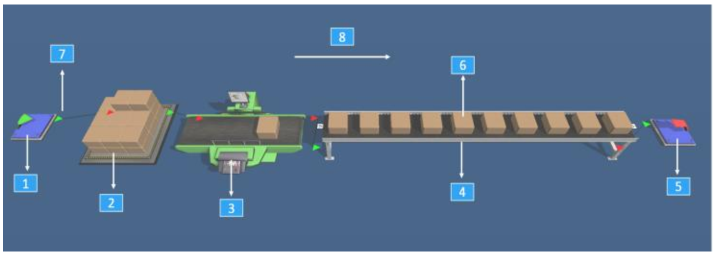
Component	Description
The frame of the belt conveyor	Material: Aluminum
	1200 x 215 x 600 mm
Belt conveyor	Material: Rubber
	1000 x 120 mm
Head pulley drive motor	Stepper Nema 23 57 Hanpose 220 Ncm
Pneumatic	Work pressure: 0,8-1 Mpa,
	Actuator stroke length: 100 mm
Microprocessors	Arduino Uno
Box size	Material: Acrylic
	Mass: 97,13 grams
	120 x 70 x 45 mm
Box queue loading place	Capacity box: 8 box
	Material: Acrylic

2.4 Experimental Measurement

The capacity of the conveyor is measured manually by counting the number of boxes that come out at the output end of the conveyor for 15 minutes using a timer. The result of the calculation of the number of boxes is multiplied by four to obtain the capacity in hours. The measurements were repeated three times for each pair of independent variables. It was done because the mean and standard deviation trend showed the measurement results' consistency. Consistency of measurement results indicates no significant variation from one measurement to another, so it can be relied upon and used as a basis for determining valid data. During the conveying measurement period, the boxes were also continuously added to the box store, taking boxes from the boxes coming out of the output side of the conveyor. While the variable input in the form of changes in the independent variable (observation), speed, and box queue time interval, is carried out in the Arduino program. The complete results of the conveying capacity measurements are shown in Table 5.

2.5 DES Modeling Setup

The modeling application used in this research is Flexsim 2021. The modeling assembly, which was prepared before measuring the conveying capacity of the conveyor, is shown in Fig. 4.



1. Source; 2. Queue; 3. Processor; 4. Belt conveyor; 5. Sink; 6. Box; 7. Connector object; 8. Box delivery direction.

Fig. 4. Modeling a belt conveyor assembly

The time taken for the processor (Fig. 4) to process the boxes is the same as the time interval for the pneumatic rod sealer to push the boxes onto the conveyor (Fig. 2). The conveying time per box on the conveyor is set to the same value, even though the length of the conveyor is different in Fig. 2 and Fig. 4.

The calculation of the box conveying time on the belt conveyor (tbox) is based on the initial data that the length of the actual (experimental) belt conveyor, L_{exp} = 1 m, the length of the modeling belt conveyor, L_{des} = 10 m, and the diameter of the pully head, d = 48 mm. The formulas and calculation results are given in Table 3. This table is used as an auxiliary table for assuming model setting values.

Table 3. Formulas and results of the calculations Vc_{exp}, t_{box}, and Vc_{des}

N (rpm)	$Vc_{exp} = \frac{\pi \times d \times N}{60 \times 1000}$ (1) (m/det)	$t_{box} = \frac{L_{exp}}{Vc_{exp}}$ (det)	$Vc_{des} = \frac{L_{des}}{t_{box}}$ (m/det)
10	0,025	40	0,25
20	0,050	20	0,50
30	0,075	13	0,75

(1) Correlation between linear speed and head pully speed.

In addition, the variable values entered into the DES modeling application (Flexsim 2021) are shown in Table 4.

Table 4. DES modeling parameters

Parameters	Value	Units	Remarks
Conveyor belt length path	10	meter	Default value
Processing time per box [1]	- 5 - 7 - 9	second	Independent variable modeling
Conveyor belt speed [2], Vc_{des}	- 0.25 - 0.50 - 0.75	meter per second	Independent variable modeling

[1]Equals the box queuing time interval term.
[2]Values have been adapted to the experimental data (based on table 3).

2.6 Statistical Analysis Parameters

The analysis was carried out using the Minitab 2022 application, with two statistical methods used as the approach method of this research, namely descriptive statistics and inferential statistics. The descriptive statistics centered on analyzing the normality test using the Kolmogorov-Smirnov test method. Meanwhile, inferential statistics focused on analyzing the significance of the two sets of load-bearing capacity data obtained experimentally and by DES. The results of the analysis of the two tests and the methods used are shown in Table 6.

3 Results and Discussion

3.1 Results

The results of the measurements carried out using the experimental method and DES modeling on nine combinations of speed variables and box queuing time are shown in Table 5, which is intended to provide information on the performance of both methods.

Table 5. Measurement results of the conveying capacity of the belt conveyor

Speed, N (rpm)	Box queuing time (second)	Exp. capacity (boxes/jam)1	DES capacity (boxes/hour)1
10	5	594	712
10	7	444	508
10	9	360	395
20	5	642	716
20	7	480	511
20	9	372	397
30	5	720	717
30	7	510	512
30	9	390	398

[1]The average value obtained from the three replicates carried out.

The measurement was repeated only three times because the mean and standard deviation trend showed the measurement results' consistency. Consistency of the measurement results indicates no significant variation from one measurement to another, so it can be relied upon and used to determine valid data.

3.2 Discussion

3.2.1 Effect of Speed and Box Queue Time Interval on Conveying Capacity

A visual representation of the relationship between the speed and time interval of the box queue and the conveying capacity can be seen in Fig. 5. The visual representation using the "heat map" graphical model was obtained from the experimental results using the comparative quantitative analysis method. This Fig. is expected to provide the necessary information to optimize the conveying capacity of the belt conveyor.

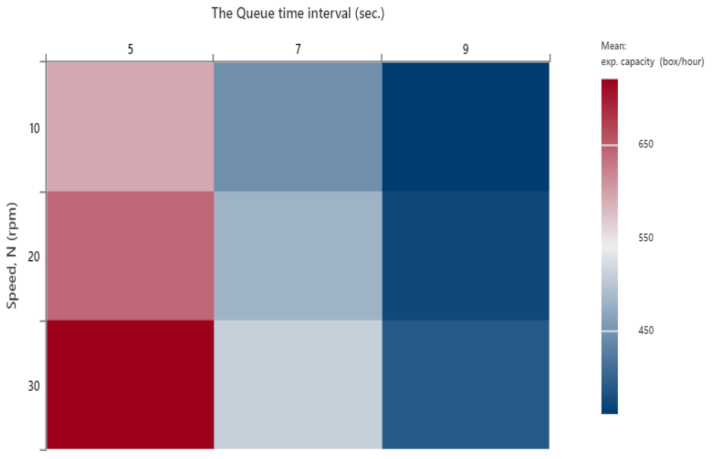


Fig. 5. Heatmap of speed and queuing time interval of boxes against experimental conveying capacity

Furthermore, Fig. 5 shows that when the box queue time interval increases while the speed remains fixed, there will be a significant decrease in the experimental conveying capacity. It can be seen by the change in the color gradient in the horizontal direction, with the magnitude of the change in the color gradient shown in the color indicator value on the right-hand side of the Fig.. Fig. 5 also indicates that when the speed increases while the box queue time interval remains fixed, the experimental conveying capacity increases significantly. It can be seen from the change in the color gradient in the vertical direction, where the magnitude of the color gradient change is shown in the color indicator value on the right side of the Fig..

In addition, a visual representation of the relationship between the speed and waiting time of the box queue and the conveying capacity can be seen in Fig. 6. The visual representation using the "heat map" graphical model was obtained from the DES modeling results using the comparative quantitative analysis method. This Fig. is expected to provide the necessary information to optimize the conveying capacity of the conveyor.

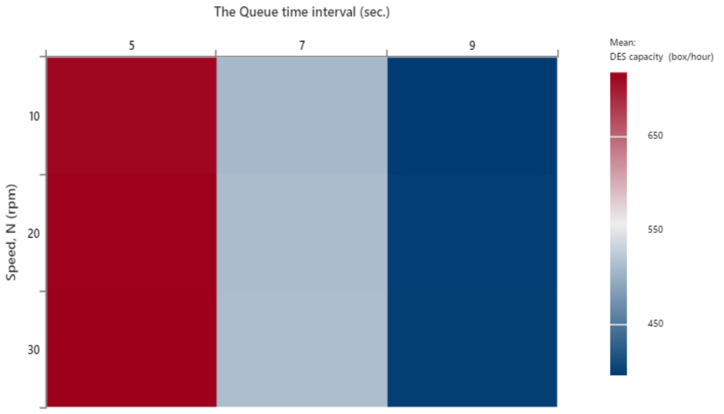


Fig. 6. Heatmap of speed and queuing time interval of boxes against DES modeling conveying capacity

In addition, Fig. 6 shows that when the box queue time interval increases while the speed remains fixed, the DES conveying capacity decreases significantly. It can be seen from the change in the color gradient in the horizontal direction, where the magnitude of the change in the color gradient is shown in the color indicator value on the right-hand side of the Fig.. Fig. 6 also shows that when the speed increases while the box queue time interval remains fixed, the DES conveying capacity increases insignificantly. It can be seen from the lack of change in the color gradient in the vertical direction, with the magnitude of the change in the color gradient shown in the color indicator value on the right-hand side of the Fig. 6.

3.2.2 Minimum and Maximum Conveying Capacity

The experimental test results, shown in Fig. 5, indicate that the minimum capacity (360 boxes/hour) was achieved at 10 rpm and a boxes queue time interval of 9 seconds. The maximum capacity (720 boxes per hour) was achieved at 30 rpm with a queue time of 5 seconds.

The test results using DES modeling, as shown in Fig. 6, indicate that the minimum conveying capacity (395 boxes per hour) is achieved at a speed of 10 rpm and a box queue time interval of 9 seconds. The maximum capacity (717 boxes per hour) was also achieved at 30 rpm with a queue time of 5 seconds.

3.2.3 An Analysis of The Concept of Causality: The Relationship between Capacity, Efficiency, and Productivity

The cause-and-effect relationship between capacity, efficiency, and productivity can be complex and depends on some factors.

The conveying capacity refers to the maximum number of boxes a conveyor can handle at a given time. Efficiency refers to the extent to which the process (conveyor) can convert inputs into outputs efficiently. Productivity refers to the amount of output a system or process can produce per input unit.

In general, increasing capacity, efficiency or productivity can lead to increased output and profits. However, it is important to note that these concepts are not mutually exclusive and can influence each other differently [19]. For example, an increase in conveying capacity can increase efficiency and productivity if the additional capacity is used effectively. However, it can also decrease efficiency and productivity if the additional capacity is not used effectively or leads to increased costs (e.g., due to the need for additional resources).

It is also possible that an increase in conveying capacity may lead to an increase in power consumption, depending on the specific situation. An increase in conveying capacity is because the head pully speed (linear speed of the conveyor belt) also increases. In some cases, increasing the head pully speed will increase power consumption. On the other hand, increasing the head pulley speed also results in precisely maintaining the conveying capacity, resulting in an efficient and productive process. Again, it should be noted that these concepts are not mutually exclusive and can influence each other in different ways [19]. Therefore, this research can continue to find an optimal solution to the problem.

3.2.4 Normality and Significance Test for Conveying Capacity

In order to determine the distribution of the data and the level of significance between the independent variables/observations on the conveying capacity of the conveyor belt, a test of normality using the Kolmogorov-Smirnov test, and a test of significance using the 2-sample unpaired test was performed on nine conveying capacity data obtained from the measurement results. The results of these tests are presented in Table 6.

Table 6. Data analysis results of the normality test and significance test

Analysis	Parameter descriptions	Exp. capacity	DES capacity
Normality test	*Mean*	501,3	540,7
	StDev	127,0	139,7
	N	9	9
	KS	0.143	0,248
	P-Value	0,150	0,108
Significance test	*Null hypothesis*	H_0: $\mu_1 - \mu_2 = 0$	
	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
	T-Value	-0.62	
	DF	15	
	P-Value	0.541	

To make it easier to understand the distribution of the data and to find out whether the data meets the criteria for normality, the results of the normality test using the Kolmogorov-Smirnov test method are presented in visual form, as shown in Fig. 7.

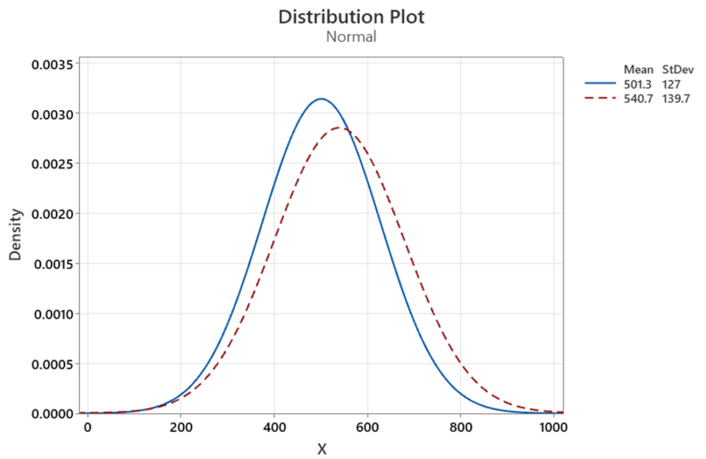


Fig. 7. The plot of normality test data

3.2.4.1 Normality Test Statement

Based on the p-value in Table 6, which are 0.150 and 0.108, the two measurement data are declared to be normally distributed. If the p-value > α = 0.05, then the data are normally distributed. Conversely, if the p-value is < α = 0.05, the data are not normally distributed [20][21]. Data are said to be normally distributed if the curve has a bell-shaped or symmetric central tendency where the left and right means are close to 50% [21].

3.2.4.2 Mean Significance Test Statement

Based on the p-value of 0.541 shown in table 6, the treatment of the two capacity data is not significantly different (hypothesis H_0: accepted). The rejection range at the significance level α=0.05 is: reject H_0 if p-value < α or accept H_0 if p-value > α [20][21].

4 Conclusion

The results showed a significant influence between speed and box queue time interval independent variables on the belt conveyor conveying capacity. If the speed is controlled and the box queuing time increases, the conveying capacity will decrease significantly. It shows that changes in the box queue time interval affect the conveyor's conveying capacity. When the interval time of the queue is controlled, and the speed of the head pully is increased, the conveying capacity of the "experiment" has increased significantly. At the same time, the conveying capacity of "DES" has also increased, but not significantly. It shows that changes in the conveyor head's speed affect the conveyor belt's conveying capacity. Based on two points above, it can be formulated that increasing the speed of the belt conveyor pully head and reducing the box queuing time interval will increase the conveying capacity of the belt conveyor. Therefore, these changes can be considered to improve the efficiency of industrial conveying systems using belt conveyors. The conveyor conveying data obtained from this study showed a nearly normal distribution (p-value "0.150 and 0.108" > α "0.05") and a high level of significance (p-value "0.541" > α "0.05"). It indicates that the data obtained is valid and can be used as a valid source of information.

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