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RESEARCH ARTICLE

Proposing a novel mathematical model for hospital pneumatic system

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ABSTRACT

Hospital Pneumatic Systems, specializing in pneumatic systems, are among the most essential components for hospitals. It offers efficient and cost-effective solutions to problems related to the transportation of various materials in hospitals. However, in existing systems, the need for compressed air is met without worrying about cost control and without depending on the sample transported, and this not only makes the system inefficient but also may cause sample degradation. The main purpose of this study is to provide speed/pressure control according to the type of material transported to eliminate the disadvantages of existing systems such as energy use and sample degradation. In this study, a new mathematical model is presented that can be used to make more energy-efficient hospital pneumatic systems. Although there are many studies on various pneumatic systems in the literature, there is not enough for the control of hospital pneumatic systems. According to the results obtained in this study, the system parameters were determined and the mathematical model of the system was obtained by using the Multivariate nonlinear regression method. A genetic algorithm was used to test the validity of the obtained mathematical model and to optimize the coefficient of the input parameters of the model. It is expected that this proposed model will contribute to the use of hospital pneumatic systems and provide a scientific and practical solution to the proposed mathematical model. The proposed mathematical model provides up to 43% more efficient transportation over the currently used system that has been tested.

1. Introduction

Pneumatic systems are used in many fields, especially in various industrial applications. Today, it is frequently preferred in industrial units due to its easy maintenance, low cost, safety, and applicability features in different processes [1]. These systems make power transmission with compressed air attractive because they are economical, clean, safe, and simple in structure [2]. There are also interesting studies on the future of systems using air as a source. The Hyperloop project [3] aims to transport people in tubes. The main idea is to reduce the frictional forces between the capsule and the capsule, which creates pressure in the tube to reduce air resistance and reuse air.

Hospital pneumatic systems, which is a specialized field of pneumatic systems, are one of the most important elements for hospitals. Pneumatic transport systems in hospitals ideally connect all units. These systems can reduce the need for medical personnel, allow staff to focus on core patient care tasks, and reduce the risk of disease transmission [4]. Pneumatic systems provide efficient and cost-effective solutions for healthcare. Hospital pneumatic systems provide high health

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safety, low operating costs, and high system efficiency. However, despite important advantages such as low cost, high force/weight ratio, and cleanliness, pneumatic systems have a non-linear structure that prevents precise control. The compressibility of the air and the nonlinearity of the pressure and friction relationship between the system elements make it difficult to control the system. These limitations imply the need for a solution with more robust controllers [5].

Pneumatic systems use air blown from a pipeline. The biggest factor controlling the efficiency of these systems is the efficient use of blown air. However, in existing systems, the demand for compressed air is met without worrying about controlling the cost and without being dependent on the sample being transported. For example, for a sample that can be transported with 3 *bar*, the system produces a constant pressure of 5 *bar*. This event causes inefficiency and wastage of energy. In addition, the overpowered air system is not only inefficient but also leads to the deterioration of the samples being transported. For example, hemolysis may occur while transporting blood samples from the pneumatic tube system [6]. In addition, in hospitals, pneumatic tube systems allow rapid transport of patient blood samples but can damage blood cells and change test results [7]. In this article, a mathematical model is proposed to make the energy source used in hospital pneumatic systems more efficient. A mathematical model was proposed using the multivariable non-linear regression method since the pneumatic systems have a non-linear structure that prevents precise control. The proposed model reduces material handling cost and is aims to prevent deterioration by generating a special pressure (transport velocity) value per sample. Although pneumatic systems are a common subject of study, studies on the control of hospital pneumatic systems are very few. The use of appropriate pressure according to the sample to optimize the system makes our study unique.

The following parts of the study are organized as follows: Section 2 gives details related works. Section 3 describes the system model is introduced by giving information about the pneumatic system design and system parameters of the proposed model. Section 4 details about the results and discussion part of the proposed model are included. Section 5 describes the conclusions.

2. Literature review

Studies on the control of hospital pneumatic systems are scarce in the literature. The most relevant studies on pneumatic systems are as follows. Control studies in the literature have focused on the rapid and precise control of pneumatic actuators. There are various studies on this subject [8–12].

For the studies on improving the performance of pneumatic conveying systems: Wamba et al. [13] investigated the place of RFID technology in the health sector. The distribution of samples in hospitals is a complex process that requires coordination between all units. One of the important parameters for the system is the transport speed. Transportation speed affects both the energy consumed by the system and the transport of the samples at the appropriate speed is an important factor that prevents sample deterioration. Lee et al. [14] propose a mixed integer programming model and a broad neighborhood search algorithm to optimize the delivery of the radioisotope F-18 used for cancer diagnosis and monitoring to minimize the delivery time. Ruan et al. [15] examined the problem of intermodal transport of drugs with fuzzy methods to improve the level of health care. In his study, Abhinandu [16] aimed to use fewer compressors by reusing and storing compressed air in pipes. A specially designed smart road is used to reduce traffic.

Studies on mathematical modeling of pneumatic systems are as follows. Zhu and Ursavas [17] proposed a mathematical model for drug delivery modeling. Campbell and Jones [18] calculated the cost to balance the safety and speed of drug delivery with a mathematical model in the event of a natural disaster. Similarly; Erbeyoglu and Bilge [19] develop a mixed-integer linear model that aims to achieve a better response by considering the effectiveness of fair delivery and drug distribution to the affected areas during a disaster. Turkowski and Szudarek [20] modeled the behavior of a pipeline transport system used to push light capsules and presented theoretically optimum solutions. Pandian et al. [21] in their study, compared the performance of the pneumatic motor with the electric motor and produced the mathematical model of the pneumatic motor. In another study, a detailed mathematical model was developed for a pneumatic actuator to provide high-performance force control for robotics and automation applications [22].

Most of the studies directly related to hospital pneumatic systems have focused on whether pneumatic conveying has a detrimental effect on blood components. In one of these studies, HPS was shown to give reliable results for transporting blood samples [23]. Another study on hospital pneumatic systems describes a general approach to obtain traffic analysis of pneumatic tube systems [24]. Mavaji et al. [25] proved that hospital pneumatic conveying systems save manpower and time, and these systems are more suitable for vertical structures. As seen in the literature, studies on HPS are very limited, and a comprehensive and effective mathematical model has not been encountered yet. In this context, this study proposes a mathematical model with a new approach that enables more efficient system utilization. This proposed model is compared with existing models in terms of energy consumption, energy efficiency, and impact on sample degradation. The innovations offered by the current study are the transport speed and pressure adjustment specific to the sample type. Transport according to sample type involves determining the transport speed and pressure of the system, taking into account the characteristics of the sample.

3. Material and method

3.1. System design

In the installation of hospital systems, HPS terminals are located at all major receiving and sending locations. These are called stations. According to this system, where the blower is the energy source of the system, various samples such as blood and urine can be transported along the transport line using routers between different stations. The system consists of tubes circulating in the hospital, sending and receiving stations, and a control center. In this system, the samples inside the carrier move horizontally and vertically between rooms, floors, and even buildings at a speed of approximately $6-7m/sec$ per second. HPS can be configured as a single-zone system or a multi-zone system. The components of such a system include the blower, transportation lines, stations, diverters, conveyors, and the central system. Figure 1 shows a basic single-zone HPS diagram.

The Pneumatic Transport System (PTS) of the Düzce University Hospital, where the experimental studies were carried out, is a computer-controlled PTS with transport tubes of different diameters, operating at a certain and constant pressure value. The system has more than 20 receiving and sending stations divided into two different regions. This PTS operates at a certain speed (6 m/s) and constant pressure (320 $mBar$).

Figure 1. Basic hospital pneumatic system diagram.

3.2. Components of the proposed model

All of the parameters used in designing the system are the most critical parameters for reducing energy costs. These parameters were determined according to the data obtained as a result of the experiments conducted in Düzce University Hospital and based on the studies in the literature and presented to the literature as a new model proposal. The entire data set was obtained as a result of experimental studies that were carried out on the of the Düzce University Research Hospital HPS and consists of 150 lines of data. Input and output parameters have been determined to adjust the transport speed according to the material to be transported in the transmission line and to make the power consumption efficient. The proposed system contains 5 parameters, where 4 of them are used for input, and 1 of them is used for output. The effect of temperature, which is one of the parameters affecting the performance of HPS, was not taken into account as it would not vary significantly between hospital rooms. Table 1 shows the range of values for the input and output parameters.

Table 1. Value ranges of system parameters.

		Min Value	Max Value
Input	Pipe Diameter (mm)	20	100
	Distance (m)	1	100
	Transport Direction Coef.	1	23
	Material Weight (g)	1	2000
Output	Pressure ($mBar$)	1	800

If an HPS is to be designed for maximum efficiency, the handling characteristics of the material to be transported must be well known. It is necessary to know the conveying characteristics, what the minimum conveying rate of the designed system is, whether there is an optimum rate at which the material can be conveyed, and what pipe diameter and air carrier ratio will be required for a given material flow rate and conveying. Also, for an existing HPS, proper handling characteristics need to be determined at what flow rate a different material needs to be conveyed. Figure 2 shows the input and output parameters of the proposed model.

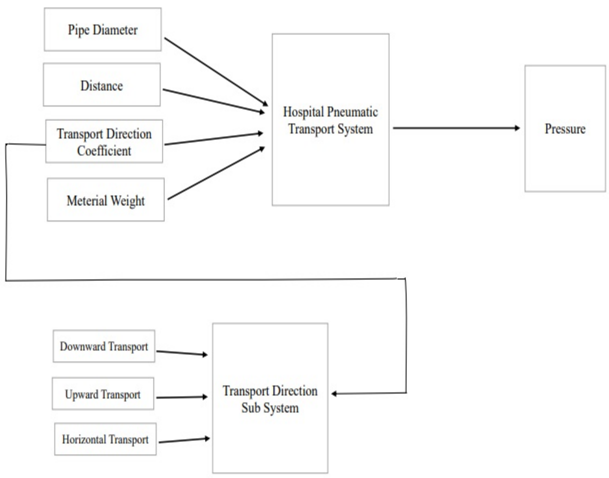

Figure 2. Model structure of the proposed system.

3.2.1. Pressure source/blower

The heavy-duty 3-phase blower was used, with a fully adjustable positioning valve, providing one system line with a variable air volume (suction and pressure).

3.2.2. Pipe/Capsule diameter

Depending on the type of material to be transported, hospitals use different pneumatic tube conveyors/capsules. For a pneumatic system to work properly, the selection of the pipe diameter of the tube to which the material will be transported is very important. As the pipe diameter increases, the power required for transmission increases. A small selection of pipe diameter causes an increase in flow rate and a pressure drop, while a large selection of pipe diameter can cause air loss. When choosing the dimensions of the capsule, the angle of the capsule should be designed in such a way that the tube does not get stuck in the turns. It should be designed so that the friction between the tube and the capsule is less [16]. Carrier and tube diameters are available in many sizes, most hospitals use 110 mm and 160 mm. Medical carriers are durable, sterilizable (autoclave 10 min at 120°C), and provided with a swivel lid which guarantees the best closure available

3.2.3. Distance

One of the important factors affecting pressure value and power consumption is the transport distance. When designing pressure conveying lines, the correct line design should be made with minimum pressure loss. Pipeline length depends on hospital size. Figure 3 shows the pressure drop due to the increase in the distance during the transportation of materials in a fixed-diameter pipeline [26].

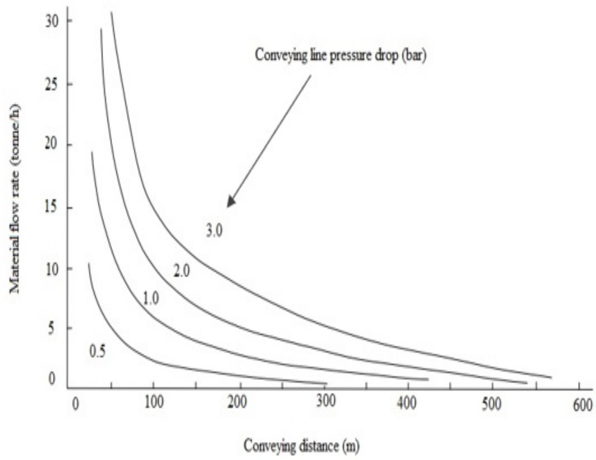

Figure 3. Effect of transport distance on pressure drop [24].

3.2.4. Material weight

Material properties (weights) and their effects on both transport conditions and material flow rate are very important. [26]. Different weights of materials such as blood samples, drugs, documents, X-Ray films, and pathology samples can be transported through pneumatic tubes. Increasing the weight of the transported material increases the required power consumption. Typical carrier loads in hospitals range from 0.1-2 kg and carrier speeds range from 3-6 m/s.

3.3. Regression analysis and proposed mathematical model

Regression analysis is a statistical method used to predict and model the relationship between different variables [27]. If the regression analysis is between more than one independent variable and the dependent variable, it is expressed as multiple regression analysis

3.3.1. Mathematical model optimization with genetic algorithm

A genetic algorithm was used to test the validity of the mathematical model obtained by using the regression method and to optimize the coefficient of the input parameters of the model. Experimental data from the hospital pneumatic systems were used with genetic algorithms and system input parameters (pipe diameter, distance, transport direction coefficient, material weight) were optimized. Constraint function has been determined in line with the needs of pneumatic systems. Values aimed for optimization were defined as genes and these genes came together to form the chromosome structure. Data on genetic algorithm structure are shown in Table 2.

Table 2. Genetic algorithm data.

Property	Values
Chromosome Count	50
Starting Population	Random
Operators Used	Crossover and Mutation Operators
Crossover Operator	Discrete Crossover
Mutation Operator	Non-Uniform
Number of Algorithm Repetitions	50
Selection Mechanism	Fitness Proportionate Selection
Algorithm Stopping Criteria	Number of Iterations (1000)

There is no huge search space to use a mathematical model in this study. However, since genetic algorithms are effective in optimizing model parameters, parameter adaptation was made using genetic algorithms and thus the performance of the model was increased. According to the results obtained by using a genetic algorithm, it has been observed that it is appropriate to use a genetic algorithm in determining the outlet pressure values of pneumatic systems. It is seen that the values obtained using this method are compatible with the coefficients of the mathematical model. This demonstrates the accuracy of the mathematical model created.

4. Results and discussions

The correlation matrix was used to determine the degree and direction of the relationship between the system parameters. Pearson's coefficient (r), which takes values between -1 and $+1$, was used to evaluate this relationship. According to the classification in the literature studies, the value of the correlation coefficient is interpreted as follows [28]:

$|r| \geq 0.8$ very strong relationship;
$0.6 \leq |r| < 0.8$ strong relationship;
$0.4 \leq |r| < 0.6$ moderate relationship;
$0.2 \leq |r| < 0.4$ weak relationship;
$|r| < 0.2$ very weak relationship.

If the r-value is greater than 0.8, it can be concluded that the two properties are highly correlated. The correlation coefficients between system parameters are shown in Table 3. According to the results, there was a strong positive relationship between the pressure (P) and pipe diameter (Pd) parameters, with a value of +0.914985. It was observed that the correlation coefficients of the other parameters were low. This experimental result indicated that there was no strong linear relationship between the variables. In addition, there was a negative relationship between the pressure and the direction-of-transport parameter. The parameters in the table are as follows: P: Pressure, Pd: Pipe Diameter, D: Distance, Tdc: Transport Direction Coefficient, and Mw: Material Weight.

Table 3. Correlation matrix for system parameters.

	Pd	D	Tdc	Mw	P
Pd	1				
D	−0.01911	1			
Tdc	−0.09559	0.052842	1		
Mw	0.118139	0.037434	0.092037	1	
P	0.914985	0.285	−0.03275	0.099406	1

The air compressor/blower is the basic and essential part of the system as it supplies compressed air. For this reason, the determination of compressed air consumption and compressor capacity is an important planning issue. By making proper planning, uneconomical compressed air costs can be reduced. Compressed air production, which is used more than necessary, causes both energy loss and an increase in losses at leakage points [29]. The efficiency of the system is directly linked to the selection and installation of various system components. Therefore, it is crucial to install compressed air systems under ideal conditions. This involves factors like determining compressor capacity and quantity during project design, sizing and setting up the compressed air system, designing appropriate circuits and selecting elements for pneumatic control circuits, and conducting necessary maintenance to ensure the longevity of these components. Another vital consideration is to avoid excessive compressor pressure, which can lead to wasted energy and the deterioration of transported materials. Thus, it's essential to generate pressure in accordance with actual requirements. The design of a pneumatic system conveying lines is one of the most important parameters affecting system efficiency [4]. The transport direction coefficient is used to distinguish the situations that require maximum power during transportation from those that require less power. The length of the pipeline, the number of horizontal, and vertical orientations, and the number of bends in the pipeline form the pipeline from geometry. Using the pipelines as straight as possible reduces the high losses in the elbows [29]. The friction distribution changes depending on the piston movement directions [30]. Since the friction force acting on each conveying direction is different during pneumatic conveying, the pressure value to be applied is different. For example, the pressure required to activate a horizontal carrier is different and less than the pressure required to move a vertical carrier. Properties such as air compressibility and friction force make pneumatic systems non-linear [22]. For this reason, there are non-linear relationships between pneumatic system variables. The multivariable nonlinear regression method can be used to express this relationship.

The simple form representation of nonlinear regression models is as follows:

$$Y_i = f\left(X_i + \gamma\right) + \epsilon. \tag{1}$$

It is the uncorrelated error term such that $E(e) = 0$ and $Var(e) = \sigma 2.f(x_i, \gamma)$ is called the expectation function for the nonlinear regression model [31]. The most used methods for parameter estimation of nonlinear regression models are least squares, maximum likelihood, and Gaussian Newton methods [32].

Mathematical modeling is defined as the process of expressing real-life components with mathematical representations [33]. The general model for a volume of gas consists of the equation of state, conservation of mass, and energy equation. The equation should be written for each room, using the assumptions that the gas is ideal, the pressure and temperature in the room are homogeneous, and the kinetic and potential energy terms are negligible. Considering the control volume V, density ρ, mass m, pressure P, and temperature T, the ideal gas equation is:

$$P = p \cdot R \cdot T. \tag{2}$$

In the literature [34], the two basic equations that consider flow variation in pneumatic systems are:

$$\frac{\partial p}{\partial s} = -R_i \cdot u - \rho \cdot \frac{\partial \omega}{\partial t}, \tag{3}$$

$$\frac{\partial u}{\partial s} = -\frac{1}{\rho \cdot c^2} \frac{\partial \rho}{\partial t}. \tag{4}$$

P is the pressure through the tube, u is the velocity, ρ is the air density, c is the sound velocity, s is the tube axis coordinate R_i is the tube resistance, and ∂t is the cross-sectional area.

The following assumptions were made in our study as well as in creating the models in the literature:

- Air is an ideal gas.
- The temperatures in the cylinder chambers are constant and equal to the feed tank temperature.
- Valve piston and hose dynamics are neglected.

The mathematical model of the pneumatic actuator, which can be a reference while creating the mathematical model, was proposed by Richer et al. [22]. According to this model:

$$\begin{aligned}(M_L + M_P) \cdot \frac{d}{dt} \cdot \dot{\mathrm{x}} + \beta \cdot \dot{\mathrm{x}} + F_f + F_L \\ = P_1 \cdot A_1 - P_2 \cdot A_2 - P_a \cdot A_r\end{aligned} \tag{5}$$

M_L is the external mass, M_p is the piston and rod mass, x represents the piston position, β is the viscous friction coefficient, F_f is the Coulomb friction force, F_L is the external force, P_1 and P_2 are the absolute pressures inside the chambers of the actuator. P_a is the absolute ambient pressure, A_1 and A_2 are the effective areas of the piston, and A_r is the cross-sectional area of the rod. These equations show the effect and importance of mass and friction force.

In this study, a mathematical model has been proposed to be used in the control of hospital pneumatic systems with the multi-variable nonlinear regression method using Matlab, which is a programming and numeric computing platform. The output parameter of the obtained mathematical model is the pressure value expected to be produced by the system. The purpose of the system is to control the pressure value that the blower should produce, which is the output parameter. According to the proposed mathematical model, the pressure value that the system should produce is determined according to the material to be transported. Pressure measurement is easier than velocity measurement and allows the use of cheaper materials. For this reason, the pressure value was selected as the output parameter instead of the speed, and the control of this value was provided with the help of a mathematical model. Pressure/velocity-controlled transport provides the opportunity to transmit laboratory materials, blood, etc. samples without any damage. This is only possible with speed/pressure control. Input parameters are Conveying Tube Diameter/ Capsule Diameter, Distance, Material Weight, and Transport Direction parameters. The obtained non-linear regression model and the parameters of the model are as follows: P: Pressure, Pd: Pipe Diameter, D: Distance, Tdc: Transport Direction Coefficient, and Mw: Material Weight.

$$\begin{aligned} P =& 0.20607 + (0.68846 \times Pd)^2 \\ &+ (0.28 \times D)^2 + (0.28 \times Tdc)^2 \\ &- 0.017623 \times Mw^2 \end{aligned} \tag{6}$$

The R-squared and p-value of the proposed mathematical model were obtained as 0.851 and $3.71e-60$, respectively. These values show that the proposed model is statistically significant and successful.

Research on modern control applications of pneumatic systems has become very popular in recent years. Hospital pneumatic systems provide high health safety, low operating costs, and high system efficiency. However, the measures to be taken for energy and cost savings in pneumatic systems should also be evaluated with system-specific data. A poorly designed system can lead to inefficiency. Multiple steps in the hospital pneumatic conveying process affect efficiency and increase the risk of contamination. Therefore, performance is very important for these systems. A properly designed hospital pneumatic system should be optimized to use the least air at the lowest possible pressure, and it is aimed to provide the lowest air demand. Keeping energy efficiency at the highest level in hospital pneumatic systems is also the main purpose of this study. However, in existing systems, the demand for the compressed air system is met at a constant value without worrying about controlling the cost and without being dependent on the sample being transported. This causes inefficiency and waste of energy. In addition to this, the overpowered air system is not only inefficient but also leads to the deterioration of the samples being transported. Pneumatic systems are not suitable for handling sensitive or non-carrying materials. One of the aims of our study is to provide speed control and to allow sensitive samples to be transported in hospital pneumatic systems. However, since pneumatic systems have a non-linear structure, difficulties in modeling these systems and applying control algorithms are encountered.

This study includes a mathematical model proposal to be used in the control of hospital pneumatic systems. In the existing systems used in hospitals, each sample is transported at the same pressure and velocity regardless of its characteristics, while the proposed model aims to carry the material at the most appropriate value. In the proposed mathematical model, the system input parameters are (i) pipe radius, (ii) transport distance, (iii) transport direction coefficient, and (iv) transported material weight. Using this model, it was tried to obtain the most appropriate pressure output according to the material carried in the system. The mathematical model was obtained by the multi-variable nonlinear regression method. When the statistical performance of the model was revealed. According to the experimental result, the R-squared and p were obtained as 0.851 and $3.71e - 60$, respectively. Considering that the model detects nonlinear relationships, this value makes it even more meaningful. Increasing the dataset can improve the performance of this model. The results show that the nonlinear regression method is a successful method that can be used in pressure modeling and the proposed model offers an effective and efficient solution to the use of hospital pneumatic systems. The proposed model could result in a significant cost reduction. In addition, minimizing the energy loss of the system and transporting at a suitable speed for the material type will prevent unnecessary wear of the system elements and hemolysis of the samples.

To evaluate the effectiveness of the proposed mathematical model, experimental studies were carried out by transporting materials of different types, weights, and different transport properties in the system. Considering the transport conditions, the samples and conditions of the max and min power values that the system should produce are given in Table 4. These materials are of 5 different types: blood, urine, drugs, x-rays pictures, and documents. The distance and transport direction between the sending and receiving units are different for each sample type. The results produced by the current system and the proposed model were compared and the following results were obtained.

Table 4. Comparison of existing and proposed systems

Sample type	Current System Pressure ($mBar$)	Proposed Model Pressure ($mBar$)
Blood	320	198
Urine	320	240
Drug	320	300
X-Ray pictures	320	320
Document	320	180

According to this table, the proposed model produces a pressure value for different types of samples, according to the sample's carrying properties. While the current system carries the same speed/pressure value for each sample, the value is produced according to the sample property carried according to this proposed model. The data obtained show that the proposed model provides efficiency in different value ranges according to the properties of the material to be transported. According to the table, the most energy gain was obtained while the material in the document type was being transported, while there was no change in the value produced in the system during the X-Ray transport. The reason for this is the occurrence of situations that require maximum power during the transportation of this material (such as vertical and longest-distance transportation). When the data obtained is evaluated, it is seen that the proposed model can provide up to 43% efficiency to the existing pneumatic conveying system.

This study provides a perspective on the determination of the most valuable system parameters for hospital pneumatic systems and the factors that should be considered in the installation of these systems in the hospital. Pressure/velocity control according to the type of sample to be transported in the system will contribute to the prevention of unnecessary energy consumption and sample deterioration. Also, the proposed system will make a significant contribution to reducing the material handling cost. It will also be possible to transfer the types of samples that are not suitable for transport (e.g. sensitive samples) in systems with speed/pressure-controlled transport. Thus, the variety of materials that can be transported in these systems will increase. The proposed model will reduce unnecessary energy waste and material wear and will ensure that the system elements can be used for a longer period.

One of the assumptions of the model is to ignore the temperature differences in the hospital building where the system is used. Since the temperature difference between different units in these buildings varies so little it is not important. This difference has been ignored. Moreover, this developed model can also be applied to pneumatic systems in different hospitals. Overall, the development of a mathematical model for a hospital pneumatic system can help to optimize system performance, reduce energy consumption, and improve cost-effectiveness.

5. Conclusion

In this study, a mathematical model was developed to be used in the control of hospital pneumatic systems and the following results were obtained.

1. Modifying the current system of the proposed mathematical model provides up to 43% more efficient transportation.
2. The results obtained from the genetic algorithm demonstrate its compatibility with the mathematical model in determining pneumatic system outlet pressure values, thus affirming its suitability for pneumatic systems and enhancing the validity of the mathematical model.
3. Special solutions can be provided according to needs, allowing control of the system's energy requirements and optimizing workload.
4. It has been observed that faster/slower transport can prevent cases such as sample deterioration and hemolysis, depending on the sample feature.
5. Speed adjustment according to the sample feature will allow more sensitive samples to be transported in the system.
6. The safe transport of various sample types in the system ensures the elimination of material-based contagion risks and guarantees their secure conveyance.
7. Reducing material wear is possible by preventing unnecessary power consumption in the system, thereby extending the system's operational lifespan.
8. The ease of implementation of the proposed model makes it suitable for systems of varying scales.
9. The developed model provides a control for the blowers of existing hospital pneumatic systems. It can be used via a controller on any type of pneumatic system that is applied in various industries.

10. The most valuable contribution of the proposed model is that it can be integrated into different pneumatic systems, optimizing the energy consumption of these systems and allowing the transportation of different types of samples without damage or the need for re-sampling.

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