



Logistics and Distribution Management

Effect of the Friction Coefficient on the Efficiency of Goods Handling in Warehouses

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A B S T R A C T

This study is motivated by the importance of efficiency in material handling within warehouse logistics systems, which is influenced by physical factors, particularly the coefficient of friction of floor surfaces. The objective of this research is to analyze the effect of the coefficient of friction on pushing force and the operational efficiency of material handling in warehouses. The method employed is a direct experimental approach by moving a 10 kg load using a trolley over a distance of 5 meters on three types of surfaces: ceramic, wood, and carpet. Each treatment was repeated 20 times. The observed variables include pushing force, travel time, work, efficiency, and coefficient of friction, which were subsequently analyzed using descriptive and inferential statistics. The results indicate that an increase in the coefficient of friction significantly increases the required pushing force and travel time, while reducing system efficiency. The ANOVA test produced a significance value of 0.000 (<0.05), indicating a significant difference among the surface types. Furthermore, Pearson correlation analysis revealed a very strong relationship between the coefficient of friction and pushing force ($r = 0.990$). Ceramic surfaces yielded the highest efficiency compared to wood and carpet. The study concludes that selecting floor materials with a low coefficient of friction can significantly improve the operational efficiency of material handling in warehouses, making it an important consideration in logistics system design.

1. Introduction

In logistics systems, the efficiency of goods handling is crucial for reducing operational costs. One of the main factors is the friction force between surfaces and handling equipment [1]. This study aims to analyze the relationship between the coefficient of friction and the efficiency of goods handling. Operational efficiency in warehousing systems is one of the critical aspects in supporting modern supply chain performance. The process of moving goods that requires large pushing forces has the potential to increase energy consumption, extend working time, and raise overall operational costs. This condition can directly affect the productivity and effectiveness of the distribution process [2].

One of the physical factors influencing the goods handling process is the coefficient of friction between handling equipment, such as trolleys or pallet movers, and the warehouse floor surface [3]. A higher coefficient of friction increases the force required to move the load, thereby affecting the operational performance of the system.

In the context of industrial engineering and logistics, understanding the relationship between the coefficient of friction, driving force, and operational efficiency is very important as a basis for decision-making in warehouse floor design, selection of material handling equipment, and optimization of material handling processes. One of the physical factors influencing this process is the friction force between trolley wheels or the base of goods and the floor surface. The greater the friction force, the greater the force required to move the goods [4].

However, studies that specifically examine the effect of the coefficient of friction on the pushing force and operational efficiency in warehouse systems remain relatively limited. Most previous studies have focused more on basic mechanics and theoretical analysis, without integrating repeated experimental testing accompanied by inferential statistical analysis.

In addition, studies that link physical parameters with practical implications for energy efficiency, operator productivity, and logistics operational costs are still rarely found. Yet, such information is very important for designing effective and efficient material handling systems.

Based on this research gap, this study aims to analyze the effect of the coefficient of friction on the required pushing force and its implications for operational efficiency in the goods handling process in warehouses through a direct experimental approach and statistical analysis. The results of this study are expected to produce a quantitative model as a basis for selecting warehouse floor materials and optimizing the use of material handling equipment.

One of the phenomena commonly encountered in daily life is friction. Frictional force is an interesting topic to study in physics education [5]. Friction arises due to the relative motion between two contacting surfaces, causing movement between them to become restricted and hindered. The greater the frictional force, the stronger or more “adherent” the contact between the surfaces [6]. Friction occurs when two objects are in contact, and its direction is opposite to the direction of motion of the object, or tends to oppose the direction in which the object is about to move [7]. Friction is influenced by the roughness level of the surfaces in contact as well as the normal force between the two objects [8]. Surface roughness affects the coefficient of friction at the contact interface.

The frictional force acting when an object moves relative to another medium is called kinetic friction. One way to study friction is by sliding an object on an inclined plane system [9]. An object placed on an inclined plane will slide when the component of gravitational force parallel to the plane is greater than the maximum static friction force. When the object is in motion, the friction acting on it is kinetic friction.

Experimentally determining the coefficient of kinetic friction using conventional methods is relatively complex, involving many parameters that must be collected and analyzed. Manual observation of the travel time of an object along an inclined plane also requires careful attention and is difficult to perform, especially for relatively short track lengths [10].

This study was conducted to determine the relationship between the coefficient of friction and the efficiency of goods handling through direct experimentation.

2. LITERATURE REVIEW

2.1. Basic Concepts of Frictional Force

Frictional force is one of the most commonly encountered physical phenomena in both daily life and industrial applications. It is also an interesting topic in physics education due to its wide relevance [11]. Friction arises due to the relative motion between two contacting surfaces, causing the movement of an object against another to be hindered [12]. The greater the frictional force, the stronger the interaction between the two surfaces.

Friction occurs when two objects are in contact, and its direction is opposite to the direction of motion of the object or tends to oppose the direction in which the object is about to move. This characteristic makes friction a force that always acts to resist motion [6]. The factors that influence the magnitude of frictional force include the surface roughness of the two contacting bodies and the contact force between them, known as the normal force [8]. Surface roughness directly affects the coefficient of friction at the contact interface [13].

Mathematically, the relationship between frictional force, coefficient of friction, and normal force can be expressed by the following equation:

$$f = \mu \times N$$

where f is the frictional force (Newton), μ is the coefficient of friction (dimensionless), and N is the normal force acting perpendicular to the contact surface (Newton). This equation applies to both the static friction coefficient (μ_s) and the kinetic friction coefficient (μ_k).

2.2. Static and Kinetic Coefficients of Friction

In applied physics studies, there are two types of friction coefficients relevant to the analysis of goods handling, namely the static friction coefficient (μ_s) and the kinetic friction coefficient (μ_k). The static friction coefficient represents the magnitude of frictional resistance when an object is still at rest and about to start moving, whereas the kinetic friction coefficient represents the frictional resistance when the object is already in motion.

Previous studies have analyzed static and kinetic friction coefficients on various material surfaces, such as wood, glass, and aluminum, through experiments involving object motion on inclined planes. The results show that the value of the static friction coefficient (μ_s) is generally higher than the kinetic friction coefficient (μ_k) across various material pairings [14]. This finding is consistent with the physical principle that the force required to initiate motion is always greater than the force needed to maintain motion.

Other studies have also examined kinetic frictional force acting when an object moves relative to another surface using an inclined plane system. Under certain conditions, an object placed on an inclined plane will begin to slide when the component of gravitational force parallel to the plane exceeds the maximum static friction force. Once the object starts moving, the friction acting on it becomes kinetic friction [15]. This approach is widely used in experimental research to accurately determine the coefficient of friction.

Another study analyzed static and kinetic friction coefficients for various material surface pairs on an inclined plane using video tracking analysis applications. The results showed that the lowest coefficient of friction was observed for the tile–tile surface pair (0.291 ± 0.004), while the highest value was found for the aluminum–wood pair (0.65 ± 0.013) [16]. These findings demonstrate that the type of surface material significantly influences the magnitude of the friction coefficient.

2.3. Factors Affecting the Coefficient of Friction

The coefficient of friction is influenced by several factors that need to be understood in the context of warehouse material handling. Frictional force is affected by two main factors, namely the surface roughness of the two contacting bodies and the contact

force between them (normal force). Surface roughness is an important parameter because it is directly related to the physical characteristics of warehouse flooring materials and the bases of handling equipment used [17].

Research on the testing of friction coefficients of plate surfaces with variations in lubrication shows that surface roughness significantly affects the coefficient of friction. Under dry conditions, the rougher the surface, the greater the friction angle and the coefficient of friction. However, the use of lubricants with certain viscosities can alter this relationship pattern [18]. These findings provide important implications for the selection of flooring types and handling equipment in warehouse environments.

3. METHODOLOGY

The research method used is a quantitative experimental approach with a simulation of load transfer on various types of surfaces. A load of 10 kg was moved over a distance of 5 meters using a trolley. Variations in the coefficient of friction were determined based on the type of surface, namely ceramic/iron ($\mu = 0.2$), wood ($\mu = 0.3$), and rubber/carpet ($\mu = 0.5$).

The frictional force is calculated based on the relationship:

$$F = \mu N$$

The work (W) performed during the transfer is formulated as:

$$W = F \cdot s$$

System efficiency is calculated by comparing ideal work to actual work:

$$\eta = \frac{W_{ideal}}{W_{aktual}} \times 100\%$$

Data collection was carried out through 20 repetitions for each type of surface to improve reliability and minimize measurement errors. The observed variables include pushing force (N) and travel time (seconds), which are then used to calculate work, coefficient of friction, and efficiency.

Data processing techniques include descriptive statistical analysis (mean and standard deviation) as well as inferential analysis in the form of ANOVA tests to examine differences between groups, Pearson correlation analysis to assess relationships between variables, and linear regression to model the effect of the coefficient of friction on force and efficiency.

4. RESULTS AND DISCUSSION

4.1. Data Processing Results

The results of data processing from the experiment on the effect of surface type on frictional force, work, and the efficiency of object movement are presented. The surface variations used include ceramic, wood, and carpet, each of which has different roughness characteristics and contact interactions. The analyzed parameters include the average frictional force, standard deviation (SD), coefficient of friction (μ), work required to move the object, and system efficiency. The processed data are presented in Table 1.

Table 1. Data Processing Results

Surface	\bar{F} (N)	SD	μ	Work (J)	Efficiency (%)
Ceramic	19.0	1.0	0.19	95.0	100.0
Wood	29.0	1.0	0.29	145.0	65.52
Carpet	46.0	1.0	0.46	230.0	41.3

Based on the obtained data, it can be observed that the type of surface has a significant effect on the values of frictional force, coefficient of friction, work, and relative efficiency. The ceramic surface shows the lowest frictional force value, namely 19.0 N with a coefficient of friction of 0.19. This indicates that the ceramic surface has a relatively low level of roughness, resulting in minimal interaction between the two surfaces. Consequently, the work required to move the object is also the lowest, namely 95.0 J. The relative efficiency value of 100% for this surface is obtained because it is used as the reference condition with minimum work. In this study, relative efficiency is defined as the ratio of minimum work to the work on each surface; therefore, lower values indicate higher energy requirements due to increased frictional force.

In contrast, the carpet surface shows the highest frictional force value, namely 46.0 N with a coefficient of friction of 0.46. This high value is caused by the rough and fibrous structure of the carpet surface, which increases the resistance to object movement. As a consequence, the required work increases to 230.0 J, while system efficiency decreases significantly to 41.3%.

The wood surface is in an intermediate condition, with a frictional force value of 29.0 N and a coefficient of friction of 0.29. The required work is 145.0 J with an efficiency of 65.52%. This indicates that wood has a moderate level of roughness, resulting in frictional force and efficiency values between those of ceramic and carpet.

Overall, the results of this study show that as the coefficient of friction of a surface increases, the force and work required to move an object also increase, while the resulting efficiency decreases. This relationship confirms that the material surface characteristics play an important role in determining the performance of object handling systems.

4.2. Mathematical Analysis

Mathematical analysis was conducted to quantify the relationship between the physical parameters involved in the object transfer process on various types of surfaces. The calculations include the mean force, standard deviation, coefficient of friction, work, and system efficiency using relevant mathematical equations. This approach aims to provide a quantitative basis for interpreting the experimental results and evaluating the consistency of the obtained data. Through this analysis, the relationship between frictional force and transfer system performance can be explained in a more systematic and measurable manner.

Mean:

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

Standard deviation:

$$SD = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}}$$

Coefficient of friction:

$$\mu = \frac{F}{N}$$

Work:

$$W = F \cdot s$$

Efficiency:

$$\eta = \frac{W_{ideal}}{W_{aktual}} \times 100\%$$

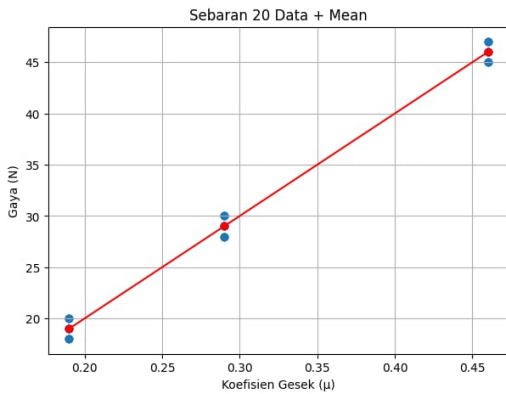


Figure 1. Data Distribution

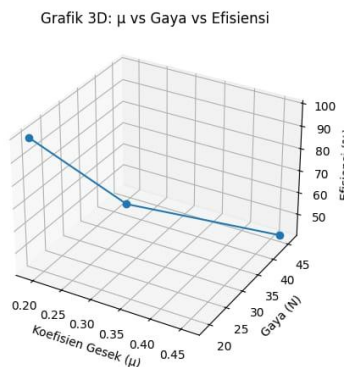


Figure 2. 3D Graph of Coefficient of Friction, Force, and Efficiency

The average force values for ceramic, wood, and carpet are 19.00 N, 29.00 N, and 46.00 N, respectively. The small standard deviation indicates that the experimental results are consistent.

The results show a linear relationship between the coefficient of friction and force. Efficiency decreases as the coefficient of friction increases because more energy is dissipated in overcoming friction. In a warehouse context, the use of low-friction materials can significantly improve operational efficiency. The greater the coefficient of friction, the greater the force required to move goods. This leads to a significant reduction in system efficiency. The small error bars indicate that the experimental data are stable and reliable.

4.3. Statistical Analysis

Analysis of Variance (ANOVA) was used to evaluate the significance of differences in mean pushing force across various types of surfaces. This approach enables the identification of the effect of treatment variations on the observed response in a statistical manner. The results of the analysis are presented in Table 2.

Table 2. ANOVA Analysis

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7533.20	2	3766.60	7160.80	0.000
Within Groups	30.00	57	0.53		
Total	7563.20	59			

Based on the ANOVA test results, an F-value of 7160.80 was obtained with a significance value of 0.000. Since the significance value is less than 0.05, there is a statistically significant difference in pushing force among the three types of surfaces.

Table 3. Descriptive Statistics

Variable	N	Mean	Std. Deviation	Minimum	Maximum
Ceramic	20	19.00	0.73	18	20
Wood	20	29.00	0.73	28	30
Carpet	20	46.00	0.73	45	47

Based on the descriptive analysis, the highest average pushing force was observed on the carpet surface at 46 N, while the lowest was on the ceramic surface at 19 N.

Table 4. Pearson Correlation

Variable	μ	Force	Sig. (2-tailed)
μ	1.000	0.990	0.000
Force	0.990	1.000	0.000

The Pearson correlation coefficient of 0.990 indicates a very strong and positive relationship between the coefficient of friction and pushing force.

Table 5. Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error
1	0.990	0.980	0.979	0.50

The coefficient of determination of 0.980 indicates that 98% of the variation in pushing force is influenced by the coefficient of friction. The results show an ANOVA significance value of 0.000, meaning there is a significant difference among the three surfaces. The Pearson correlation value of 0.990 indicates a very strong relationship between the coefficient of friction and pushing force. The R Square value of 0.980 shows that 98% of the variation in pushing force can be explained by changes in the coefficient of friction.

5. CONCLUSION

This study shows that the coefficient of friction has a highly significant effect on pushing force, work, and efficiency in warehouse material handling processes. The experimental results demonstrate that an increase in the coefficient of friction consistently leads to higher required pushing force and greater work input, which ultimately results in a decrease in system efficiency. These findings are supported by statistical tests, where ANOVA analysis shows a significant difference among surface types (sig. 0.000 < 0.05), and Pearson correlation analysis indicates a very strong and positive relationship between the coefficient of friction and pushing force (r = 0.990). In addition, the coefficient of determination (R² = 0.980) indicates that most

of the variation in pushing force can be explained by changes in the coefficient of friction.

In practical terms, the results of this study indicate that the selection of low-friction flooring materials, such as ceramic, can significantly improve the operational efficiency of goods handling compared to high-friction materials such as carpet. The implications of these findings are highly relevant to warehouse logistics system design, particularly in efforts to optimize energy use and improve work productivity. Therefore, the surface characteristics of materials should be a key consideration in the design and management of storage facilities to achieve optimal operational efficiency.

REFERENCES

- [1] Z. Guo *et al.*, "Modeling and simulation of friction mechanism in load-bearing wheels," *J. Phys. Conf. Ser.*, vol. 3043, no. 1, p. 012087, Jun. 2025, doi: 10.1088/1742-6596/3043/1/012087.
- [2] P. Zajac, "Energy Consumption of Transfer Points in Passive and Plus-Energy Warehouses—A Systemic Approach to Internal Transport," *Sustainability*, vol. 17, no. 21, p. 9419, Oct. 2025, doi: 10.3390/su17219419.
- [3] P. Telek, "Exploring the operating characteristics of industrial trucks for various tests of material handling systems," *Adv. Logist. Syst. - Theory Pract.*, vol. 19, no. 2, pp. 53–62, Jul. 2025, doi: 10.32971/als.2025.011.
- [4] M. Pelic *et al.*, "Performance of power-assist transport cart drive," *Adv. Sci. Technol. Res. J.*, vol. 19, no. 2, pp. 383–392, Dec. 2024, doi: 10.12913/22998624/196707.
- [5] L. Radenkovic, J. Delibasic, and L. Nestic, "Influence of sliding speed and normal force on dry and wet friction: an experimental study," *Rom. Reports Phys.*, vol. 77, no. 2, pp. 905–905, Jun. 2025, doi: 10.59277/RomRepPhys.2025.77.905.
- [6] F. Andriani, S. S. Busri, W. Rande, Y. M. Joni, and R. B. Astro, "ANALISIS KOEFISIEN GESEK KINETIS BENDA DI BIDANG MIRING MENGGUNAKAN VIDEO TRACKER," *Opt. J. Pendidik. Fis.*, vol. 5, no. 1, pp. 74–83, Jun. 2021, doi: 10.37478/optika.v5i1.980.
- [7] A. U. Prastyo, P. Hermawan, E. Salsabila, F. C. Sari, and K. Kurniawanti, "Eksperimen Gaya Gesek Pada Bidang Miring Untuk Menguji Koefisien Gesek Statis Dan Kinetis," *J. Ind. Eng. UPY*, vol. 1, no. 1, pp. 1–8, 2022, doi: <https://doi.org/10.31316/jie.upy.v1i1.2365>.
- [8] A. A. Putera, S. Jivani, S. Zahra, and M. N. Hadi, "Analisis Perbandingan Gaya Gesek Pada Objek Kayu Juga Logam Serta Manusia Menggunakan PHET Simulation," *J. Media Akad.*, vol. 3, no. 12, pp. 1–10, 2025, doi: <https://doi.org/10.62281/dwxsec76>.
- [9] M. A. A. C. Bug-os, S. J. Marte, and U. B. Pili, "Verification experiment of the coefficient of static and kinetic friction utilizing a mobile application," *Phys. Educ.*, vol. 58, no. 6, p. 065013, Nov. 2023, doi: 10.1088/1361-6552/acf431.
- [10] D. Luo, "Using an electronic balance to measure the kinetic friction coefficient in class experiment," *Phys. Educ.*, vol. 60, no. 1, p. 015013, Jan. 2025, doi: 10.1088/1361-6552/ad9375.
- [11] Muhammad Fadli, Annisa Kamila Insani, Kasamira Delima, and Tyrra Aulia Rahma Mahfud, "Kajian Mekanika pada Materi Pesawat Sederhana: Review Publikasi Ilmiah," *Mitra Pilar J. Pendidikan, Inovasi, dan Terap. Teknol.*, vol. 1, no. 2, pp. 171–190, Dec. 2022, doi: 10.58797/pilar.0102.09.
- [12] Challilullah, L. Permatasari, and J. V. Sirait, "Analisis Perbandingan Koefisien Gesekan Kinetik Pada Permukaan Kayu Dengan Variasi Bidang," *Edu Res.*, vol. 6, no. 4, pp. 162–178, 2025, doi: <https://doi.org/10.47827/jer.v6i4.1574>.
- [13] S. Zhang, D. Li, and Y. Liu, "Friction Behavior of Rough Surfaces on the Basis of Contact Mechanics: A Review and Prospects," *Micromachines*, vol. 13, no. 11, p. 1907, Nov. 2022, doi: 10.3390/mi13111907.
- [14] R. Astro, D. Amirudin, D. Mufida, S. Humairo, and S. Viridi, "Analisis Koefisien Gesek Statis dan Kinetis Benda di Bidang Miring Menggunakan Video Tracker," in *Seminar Kontribusi Fisika (SKF 2017)*, Bandung, 2017.
- [15] W. Kurniawan and D. Handayani, "Pengembangan Alat Peraga Fisika Pada Materi Gaya Gesek Berbasis Sensor Ultrasonik," *J. Ilmu Fis. dan Pembelajarannya*, vol. 2, pp. 49–52, 2018, doi: 10.19109/JIFP.v2i2.2748.
- [16] S. Humairo, R. Astro, D. Amirudin, D. Mufida, and S. Viridi, "Analisis koefisien gesek statis dan kinetis berbagai pasangan permukaan bahan pada bidang miring menggunakan aplikasi analisis video tracker," in *Seminar Nasional Quantum*, Yogyakarta, 2015, pp. 132–138.
- [17] Z. Fuadi, "Analisis pengaruh perbedaan koefisien gesekan statis dan kinetis terhadap gerakan stick-slip menggunakan bahan viskoelastis," *J. Tek. Mesin Indones.*, vol. 11, p. 51, 2018, doi: 10.36289/jtmi.v11i1.52.
- [18] M. B. Fitrianto, D. Darmanto, and I. Syafa'at, "Pengujian Koefisien Gesek Permukaan Plat Baja ST 37 pada Bidang Miring terhadap Viskositas Pelumas dan Kekasaran Permukaan," *Maj. Ilm. Momentum*, vol. 11, no. 1, 2015, doi: <https://doi.org/10.36499/jim.v11i1.1076>.

NOMENCLATURE

F	Frictional force / pushing force (Newton, N)
μ	Coefficient of friction (dimensionless)
N	Normal force (Newton, N)
W	Work (Joule, J)
s	Displacement distance (meter, m)
η	Efficiency (%)
$W_{(ideal)}$	Ideal work (Joule, J)
$W_{(actual)}$	Actual work (Joule, J)
m	Load mass (kilogram, kg)
g	Gravitational acceleration (9.81 m/s ²)
t	Travel time (second, s)
v	Average velocity (meter/second, m/s)
r	Pearson correlation coefficient (dimensionless)
σ	Standard deviation
\bar{x}	Mean value