

The Optimum Parameters for Material Flow Speed, Working Noise, and Material Flow Direction for Physical and Mental Workload

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Abstract

Conveyor equipment is commonly used in packaging systems, and operators must stand for long periods and perform a similar, monotonous task. This might increase the operator's physical and mental fatigue. A hypothesis is, that the speed, noise, and direction of material flow influence the operator's workload. A work system optimization could be proposed using response surface methodology. The Central Composite Design was proposed as an experimental design. Both physical and mental workload are assessed as the response. The results showed that the optimal combination of physical workload response parameters was a speed of 25.8579 cm/s, a noise of 89.3569 dB, and a flow direction from right to left. Meanwhile, the optimal parameter combination for mental workload response was a speed of 25.8579 cm/s and a noise level of 77.9289 dB, with the most optimal flow direction from right to left.

Keywords

Material Flow Speed, Working Noise, Material Flow Direction, Physical, Mental, Workload.

Introduction

A conveyor is a transportation medium designed to carry large volumes of solid objects. This equipment features a belt that serves as a transport medium. In modern industry, the conveyor system has become a critical piece of equipment in the production chain (Mahmood & Shareef, 2024; Mendes et al., 2023; Szentesi & Tamás, 2023; Butt & Jedi, 2020). Conveyors enable the efficient transportation of materials or products from one location to another without intensive manual intervention. The use of conveyors, such as those used in manual work for transporting materials or products, can reduce labor and reduce the risk of worker injury (Szurgacz et al., 2022). The efficiency and performance of conveyor operators not only affect the smooth operation of production but also influence the quality and effectiveness of the entire process.

Several factors influence the quality of operator performance in conveyor-related activities. Some of these factors are the work environment and work systems. A work environment ideal for the job, correctly, quickly,

safely, and with high productivity (Freivalds & Niebel, 2014). A study by Alves et al. (2025), Chenarboo et al. (2022), and Loske et al. (2021) found that the work environment is an external factor that can influence operator performance, including mental and physical workload. According to Szurgacz et al. (2022) and Bernardes et al. (2023), a relationship exists between standing work attitudes and workers' complaints of low back pain, suggesting that prolonged standing work positions can lead to physical fatigue and leg injuries in operators. Meanwhile, the monotonous packing procedures on conveyors also cause physical and mental fatigue among workers, as confirmed by studies by Hastoro (2022) and Hilmi et al. (2022). That monotonous, repetitive work can increase the workload.

Factors related to the work environment and work procedures observed in this study include the direction of flow, material speed, and noise levels in the working area. Several researchers have used these variables, as done by Nino et al. (2023), in relation to experimental design with moment response variables from the lumbar five sacrum (L5-S1). The results show that the operator's orientation when packing pallets on the right side of the conveyor is more optimal. In addition, research by Mendes et al. (2023) and Deka et al. (2024) indicates that conveyor speed influences work productivity. The study results in increasing the conveyor speed from 2.28 m/s to 2.89 m/s, thereby increasing the carrying capacity. This is because, as

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the speed increases, the material becomes unstable. On the other hand, a study by [Hao et al. \(2023\)](#) states that machine noise levels, as an indicator of physical workload, can influence operator performance.

PT X and PT Y are two industries that use conveyors in the packaging process. In packaging facilities, the two companies have different characteristics. In PT X, the flow direction is from left to right; otherwise, in PT Y, the flow direction is from right to left. Additionally, the two companies use different conveyor speeds. Field observations were conducted in the presence of noise at an average level of 90 dB, which persisted for up to 8 hours of work, exceeding the regulatory threshold ([Kep.51/Men/1999, 1999](#)). Meanwhile, flow direction, material speed, and work area noise are strongly suspected to be the main factors contributing to operators' physical fatigue, injuries, mental stress, and discomfort at work ([Nino et al., 2023](#)). During these observations, the NASA-TLX mental workload questionnaire was given to three operators. The results showed that the average WWL (Weighted Workload) for the three operators was 69.11, which fell within the high category, particularly for the highest indicators of physical and mental needs. Overall, based on literature reviews, field observations, and previous research ([Mendes et al., 2023](#); [Deka et al., 2024](#); [Hao et al., 2023](#)), it is reasonable to suspect that the conveyor machine's flow direction, speed, and noise can affect operator performance.

The response surface methodology is used to optimize physical and mental workload. According to [Hussain et al. \(2023\)](#), Response Surface Methodology (RSM) is a widely used method for determining the influence of each factor and its interactions. It makes the optimization process more effective. This study optimizes the physical and mental workload of conveyor operators by combining material speed, noise, and flow direction. This study will use a central composite design (CCD). CCD is one part of the experimental design of Response Surface Methodology. The CCD method can be used to evaluate the optimal response of the variable by determining the number of experiments. This CCD method has three types of points: factorial points, axial points (start points), and central points ([Szpisják-Gulyás et al., 2023](#)).

Materials & Methods

Participant

The participants involved in this study were five laboratory assistants from the Ergonomi dan Perancangan Sistem Kerja (EPSK) laboratory. The consideration of

establishing participant criteria (purposive sampling) is to ensure the accuracy of the research methodology and obtain relevant participant characteristics. This can reduce time and resources. This aligns with the research by [Memon et al. \(2025\)](#), which indicates that the purposive method is particularly effective when researchers need a well-defined group of participants who share characteristics central to the study. This is done to ensure the reliability and validity of measurements ([Ahmed, 2024](#)). In addition, the criteria for participants and pre-experimental training of operators before conducting experiments include operator selection and experimental procedures. This consideration aligns with [Ansori et al. \(2025\)](#) and [Triyanti et al. \(2024\)](#), which involve students.

In detail, the selection criteria are based on four categories, namely skill, effort, condition (work conditions), and consistency. Indicators of skill refer to participants who are confident and well-trained. Indicators of effort mean full attention to work, good speed that can be maintained, and willingness to accept suggestions. The working condition indicator is that the operator is quite comfortable with the environmental conditions. An indicator of consistency is that the operator maintains it on every job. These findings are similar to those reported by [Triyanti et al. \(2024\)](#) in a case study of the logistics industry. Apart from that, the selected participants have good health and do not have conditions such as nearsightedness, injuries, physical disabilities, or dizziness. The chosen operator is 165-175 cm tall. This height is adjusted to the height of the conveyor machine used in the experiment. The operators' ages range from 20 to 21 years old, so the differences in heart rate and physical or mental abilities are not significant. In general, these criteria align with a study by [González-Hernández et al. \(2019\)](#), which suggests that maturity begins at age 19. This research also confirms that the formal operational intellectual development stage occurs at ages 12 years and above. Since this study concerns manual interaction between workers and their work facilities (human-machine interaction), anthropometry is an important criterion, as the burden of arm reach associated with height (postural ergonomics) needs to be controlled.

Lastly, studies by [Ansori et al. \(2025\)](#), [Sapp et al. \(2023\)](#), [Riesthuis et al. \(2023\)](#), [Guo et al. \(2021\)](#), and [Digiesi et al. \(2020\)](#) show that the number of participants in the laboratory experiment may be limited. However, statistical power should be managed through the experimental design, as analytical decisions can significantly impact power, as demonstrated by [Ahmed \(2024\)](#), [Cash et al. \(2022\)](#), and [Serdar et al. \(2021\)](#). Increasing power by increasing sample size is not the only option considered. This is because

large sample sizes increase costs, making experiments more challenging to conduct. Meanwhile, research was conducted on a laboratory scale to facilitate control of confounding variables, as research by Ansori et al. (2025), Farokhmoradi & Salari-Kakhk (2025), and Appana et al. (2023) found that, to ensure responses influenced by the main ergonomic factors, management of confounding variables is required.

Variables, Apparatus, and Procedures

Participant selection is based on specific criteria. The participants were EPSK laboratory assistants. The selection criteria are based on four categories, namely skill, effort, condition (work conditions), and consistency. This research involves three independent variables: temperature, light, and noise. Noise is related to the size of the engine sound, which is adjusted according to its intensity. Meanwhile, the dependent variable is a response to work duration and a reaction to the number of errors. Determining the research factor level was informed by several previous studies (Mendes et al., 2023; Deka et al., 2024; Hao et al., 2023). Table 1 shows the factors and their levels in this study.

Table 1
Factor and level

Factor		Simbol	Level 1	Level 2
Continuous	Speed (cm/s)	C	30	50
	Noise (dB)	B	80	90
Categorical	Flow Direction	A	Left to Right	Right to Left

The study apparatus used was sound, conveyors, a Polar H10 Heart Rate Monitor, glass-bottled drinking water, cardboard, and Minitab 19 software. In detail, sound is used to measure the noise. A conveyor is needed as a material flow device. Polar H10 Heart Rate Monitor for measuring participant heart rate intervals, glass and cardboard bottles of drinking water for packaging work trials. A Minitab 19 is used to assist with the data processing. Fig. 1 shows the positions and directions of material flow in the experiments.

This study examines two aspects of workload: mental and physical. It covers two continuous factors, namely speed and noise, and one categorical factor, namely flow direction. In line with the study by Szpisják-Gulyás et al. (2023), the number of experiments can be determined using the central composite design. The calculation results showed that there were 26 repetitions in the experiments. In addition, the treatment

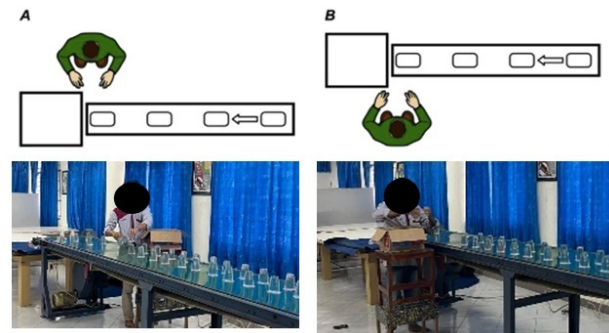


Fig. 1. Material flow direction left to right (A), right to left (B)

between factors was determined, namely, determining low axial ($-\alpha$), low factorial (-1), center (0), high factorial ($+1$), and high axial ($+\alpha$), so that the α value was obtained as in the study (Mousavi & Farivar, 2024). Before the experiment, randomization was performed on treatment combinations. Treatment combinations were randomized using a trial-order randomization.

The physical workload indicator uses the % cardiovascular load (% CVL) method. Meanwhile, mental workload is measured using the Heart Rate Variability (HRV) indicator. The procedure for collecting workload data is as follows.

1. Prepare the operator, the experimental equipment, such as the Polar H10 heart rate monitor, and pair the smartphone with the heart rate monitor to record the RR interval. Ensure the Polar H10 battery is fully charged, and the Polar H10 strap is clean and dry.
2. Place the Polar H10 heart rate monitor on the participant's chest. Place the Polar H10 on your chest, about 1-2 cm below your nipple. Ensure the elastic strap fits snugly, neither too loose nor too tight.
3. Record age and measure the resting heart rate of participants using a Polar H10 heart rate monitor.
4. Next, carry out a trial work of packing one carton of packaged glass drinks until completion using a conveyor according to the randomization order. When the operator starts work, the presses begin recording RR interval data in the smartphone application paired with the Polar H10 heart rate monitor. After the operator finishes the job, RR interval data recording is stopped by pressing the stop recording button.

Physical workload can be evaluated based on working HR and resting HR, as well as the participant's average working heart rate over time during the experiment (Hashiguchi et al., 2020). Cardiovascular load (%CVL) is calculated by dividing the difference between the working pulse and the resting pulse by the

difference between the maximum pulse and the resting pulse. The maximum pulse rate is (220-age) for men and (200-age) for women. Meanwhile, heart rate is derived from RR-interval data exported from the Polar H10 heart rate monitor, as in [Chattopadhyay & Das \(2021\)](#). Regarding mental workload, [Sutarto et al. \(2020\)](#) Reported That Heart rate variability (HRV) measures the time between consecutive R waves (the wave with the largest amplitude), which varies. This variability is influenced by the activity of the autonomic nervous system. HRV reflects a person's ability to regulate cognitive, emotional, and behavioral activities to adapt to environmental changes, and is often considered a self-regulation mechanism, as per research by [Chattopadhyay & Das \(2021\)](#).

Regarding experimental procedures, it is essential to understand them so participants can conduct the experiments as intended. Each participant will carry out 26 trials. The order of trials was random, and participants performed them according to established procedures. Technical training was given pre-experiment. Pre-experiments are conducted by training participants to perform the experiments, allowing them to become accustomed to the work. Pre-experiments are conducted a minimum of five times to enable operators to adapt, become skilled, enhance their abilities, and increase stability and consistency. This training consideration aims to validate that the research tools used are suitable for their intended purpose ([Papetti et al., 2024](#)). Apart from that, other aspects are related to local control, particularly those concerning homogeneity. Local control aims to minimize biases that can lead to heterogeneity ([Butt & Jedi, 2020](#)). The experiment was conducted in the Ergonomics and Work Design Systems Laboratory's climate chamber, where lighting, temperature, and noise are controlled. Meanwhile, Speed is technically measured by accurately measuring and marking the distance. In response to surface methodology, the tests conducted are the model significance test and the lack-of-fit test. After conducting this test, optimal parameter predictions are then made, and the optimal parameters are determined using a response optimizer.

Results and Discussion

Optimal Physical Workload

The results of the physical workload response equation model (Y_1) can be expressed as equation (1), where X_1 represents speed and X_2 represents noise. Equation one is the physical workload response equation with a flow direction factor from right to left.

The second equation is the physical workload response equation, with the flow direction from left to right.

$$\begin{aligned}
 Y_{1(1)\text{right to left}} &= 0.749 - 0.00896X_1 - 0.0136X_2 \\
 &\quad + 0.000065X_1^2 + 0.000066X_2^2 \\
 &\quad + 0.000066X_1X_2 \\
 Y_{1(2)\text{left to right}} &= 0.764 - 0.00894X_1 - 0.0136X_2 \\
 &\quad + 0.000065X_1^2 + 0.000066X_2^2 \\
 &\quad + 0.000066X_1X_2
 \end{aligned} \tag{1}$$

Regarding the model, Tab. 2 shows the analysis of variance (ANOVA) on the physical workload. Based on the ANOVA results, $F = 11.04$ ($p < 0.01$), indicating the model was significant. Meanwhile, the model deviation test (lack of fit) yielded $F = 3$ and a p -value of 0.068, which is greater than $\alpha = 0.05$ (accept H_0), indicating no effect; thus, the regression model is confirmed. The R-squared correlation value was 83.86%, which is in the strong relationship range. This means the factor strongly influences the operator's workload response variable. These results are in line with [Yung et al. \(2020\)](#), who found a positive relationship between fatigue and a reduction in quality of up to 42%.

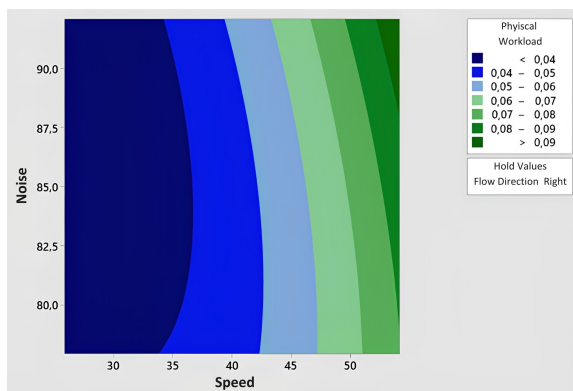
Table 2
Analysis of variance of physical workload

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	0.007454	0.000932	11.04**	0.000
Linear	3	0.006765	0.002255	26.73**	0.000
Speed (X_1)	1	0.005805	0.005805	68.82**	0.000
Noise (X_2)	1	0.000046	0.000046	0.55	0.470
Flow Direction (X_3)	1	0.000913	0.000913	10.83**	0.004
Error	17	0.001434	0.000084	–	–
Lack-of-Fit	9	0.001107	0.000123	3	0.068

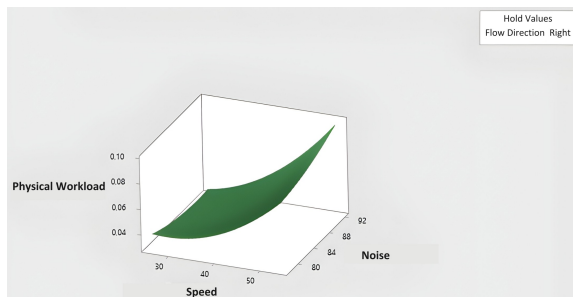
** $p < 0.01$

Optimal parameters can be observed from contour and surface plots. The two plots show the parameter range and the resulting responses. Both show the optimal area of a process for an independent variable. This relates to risk analysis, interpreting how the dependent variable changes with the independent variable, and optimizing the dependent variable by finding the optimal value of the independent variable.

Fig. 2(a) shows a contour plot of the physical workload response (Y_1) with speed factors (X_1) and noise (X_2), with the hold values obtained, namely the right flow direction (X_3). It can be seen that the optimal area (the smallest %CVL) for the physical workload is at low speed, and the physical workload increases (not optimally) as the noise level increases. Meanwhile, Fig. 2(b) shows a surface plot of the physical workload (Y_1) with speed factors (X_1) and noise (X_2), with the hold values obtained, namely the right flow direction (X_3). The surface plot shows a concave shape towards the speed factor (X_1), indicating that speed has a significant influence on physical workload.



(a) Contour plot of speed and noise (physical workload)



(b) Surface plot of speed and noise (physical workload)

Fig. 2. Plots of speed and noise (physical workload)

Fig. 3 shows the response to physical workload optimization. The graph shows that the minimum optimal physical workload is 0.0306. The optimal combination of parameters for the physical workload is a speed of 25.8579 cm/s and a noise level of 89.3569 dB, with the optimal flow direction from the right. These results suggest that an ergonomic assessment of musculoskeletal risk and sustainability evaluation is necessary to assess workers' physical needs, as noted in the study by Loske et al. (2021).

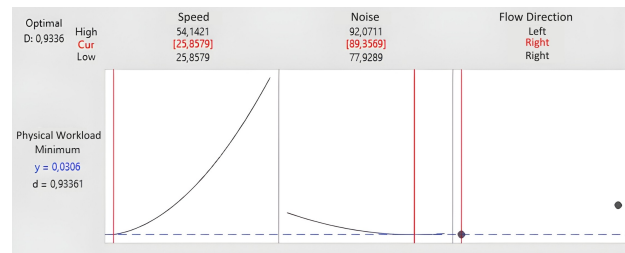


Fig. 3. Response Optimization of Physical Workload

Optimal Mental Workload

The mental workload model equation (Y_2) is as in equation (2), where X_1 is speed, and X_2 is noise. Equation one is the mental workload response equation with a flow direction factor from the right to left. The second equation is the mental workload response equation with the flow direction factor from left to right.

$$\begin{aligned}
 Y_{2(1)\text{right to left}} &= 565 - 2.27X_1 - 11.41X_2 \\
 &\quad + 0.01377X_1^2 + 0.0626X_2^2 \\
 &\quad + 0.0145X_1X_2 \\
 Y_{2(2)\text{left to right}} &= 550 - 2.25X_1 - 11.33X_2 \\
 &\quad + 0.01377X_1^2 + 0.0626X_2^2 \\
 &\quad + 0.0145X_1X_2
 \end{aligned} \quad (2)$$

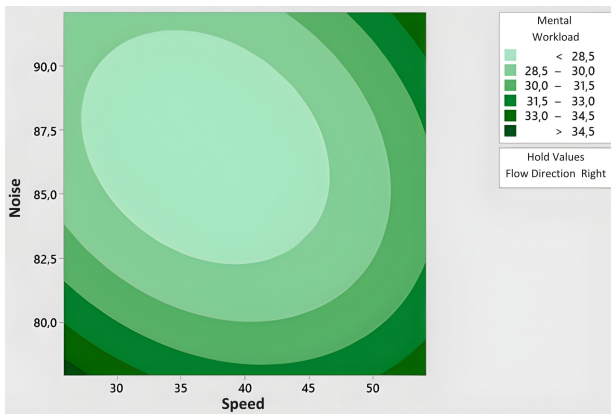
Based on ANOVA, $F = 18.48$ ($p < 0.01$) was obtained. These results indicate that there is variance (a significant model). Meanwhile, the model deviation test (lack of fit) yielded $F = 1.62$ ($p > 0.05$), indicating that H_0 was accepted. The R-squared correlation value is 79.69%, indicating a powerful relationship. This means that factors strongly influence the operator's mental workload response (Tab. 3).

Table 3
Analysis of Variance of Mental Workload

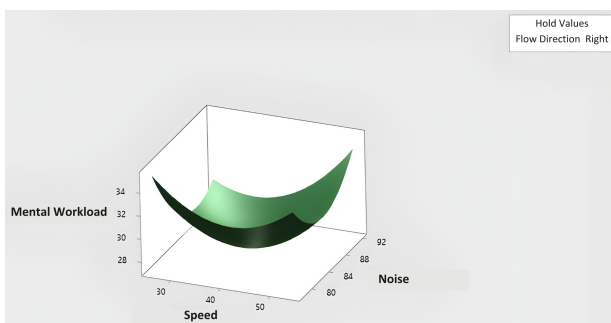
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	348.209	43.526	8.34**	0.000
Linear	3	289.482	96.494	18.48**	0.000
Speed (X_1)	1	8.343	8.343	1.60	0.223
Noise (X_2)	1	8.427	8.427	1.61	0.221
Flow Direction (X_3)	1	272.713	272.713	52.24**	0.000
Error	17	88.743	5.220	-	-
Lack-of-Fit	9	57.286	6.365	1.62	0.254

** $p < 0.01$

At this level of mental workload, both plots (contour and surface) display the parameter range and the resulting response. Fig. 4(a) is a contour plot of the mental workload response (Y_2) as a function of speed factors (X_1) and noise (X_2), with the hold values, namely the right flow direction (X_3). It can be seen that the non-optimal area (the smallest HRV) is mental workload, namely at high speed and high noise. Meanwhile, Fig. 4(b) is a surface plot of mental workload (Y_1) with speed factors (X_1) and noise (X_2), with the hold values, namely the right flow direction (X_3). The surface plot shows a concave plane with respect to the speed (X_1) and noise (X_2) factors. This indicates that speed and noise significantly affect mental workload.



(a) Contour plot of speed and noise (mental workload)



(b) Surface plot of speed and noise (mental workload)

Fig. 4. Plots of speed and noise (mental workload)

Fig. 5 shows the response to mental workload optimization. Based on the figure, the maximum optimal mental workload is 35.3530. The optimal parameter combination for mental workload is a speed of 25.8579 cm/s and a noise level of 77.9289 dB, with the most optimal flow direction factor being from the right.

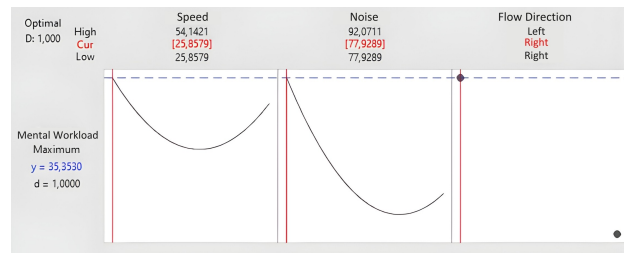


Fig. 5. Response Optimization of Mental Workload

Optimal Combination of Physical and Mental Workload

The results of both physical and mental workload are presented in Tab 4. The ANOVA reveals that the factors influencing physical workload are speed and direction of flow. In mental workload, the factor that influences mental workload is the direction of flow. The speed parameter in physical workload aligns with research (Wahyuning & Atiko, 2022), which shows that increasing speed can increase work intensity, within certain limits, thereby increasing oxygen consumption and heart rate. Additionally, studies by Mendes et al. (2023) and Deka et al. (2024) suggest that conveyor speed affects work productivity. The flow direction parameters align with research by Butt & Jedi (2020), indicating that flow direction affects the operator's workload. This is also supported by a study by de Kovel et al. (2019), which suggests that approximately 90% of the world's population uses their right hand when performing activities. This means that the direction of flow from right to left is very influential, as is the reverse.

Table 4
The comparison of ANOVA

Factor	Physical Workload	Mental Workload
Speed	Yes	No
Noise	No	No
Flow Direction	Yes	Yes

On the other hand, there are differences in the results of interference research conducted by Astuti et al. (2024), Fan et al. (2022), and Jalali et al. (2022), which found that noise exposure influenced operator workload. Differences in results may be caused by the method and the length of the experiment. In both studies, a questionnaire method was used to assess workload, with data collected from the operator's experience over time during the work (all-time series). In contrast to this study, data collection was carried out using an experimental method based on the operator's

average Heart Rate Variability for 1 minute. Fig. 6 shows the response optimization of physical and mental workload. The optimal physical workload is a minimum of 0.0383, and the optimal mental workload is a maximum of 34.5242. The optimal parameter combination for mental workload is a speed of 26.1436 cm/s and an interference of 78.5003 dB, with the optimal flow direction factor from the right.

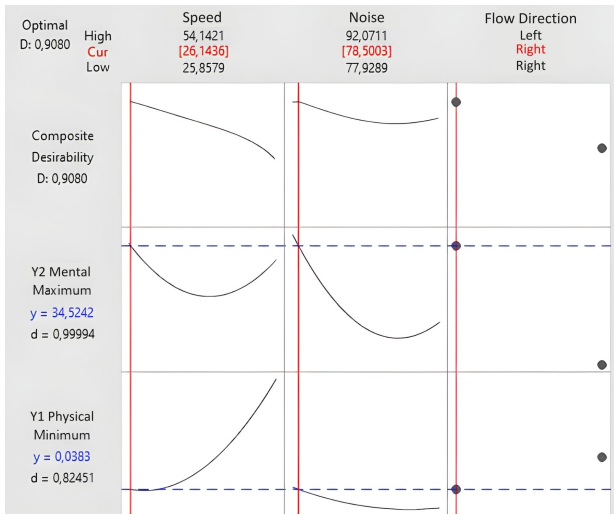


Fig. 6. Response Optimization of mental workload response

Table 5 is the result of optimizing physical and mental workload. The optimal parameter combination for the physical workload is a speed of 25.8579 cm/s and a noise level of 89.3569 dB, with the most optimal flow direction factor being from the right. The optimal parameter combination for mental workload response is a speed of 25.8579 cm/s and a noise of 77.9289 cm/s, with the optimal flow direction from the right. The difference only occurs in the noise factor. The optimal parameter combination for mental workload response is a speed of 25.8579 cm/s and a noise level of 77.9289 dB, with the most optimal flow direction from the right.

Table 5
Optimum Parameter

Response Factor	Speed (cm/s)	Noise (dB)	Flow Direction
Physical	25.8579	89.3569	Right to Left
Mental	25.8579	77.9289	Right to Left
Combination (Physical & Mental)	26.1436	78.5003	Right to Left

The results of the speed parameter optimization indicate that the speed levels are low: 25.8579 cm/s, 25.8579 cm/s, and 26.1436 cm/s. This is because increasing speed can increase work intensity, leading to higher oxygen consumption and heart rate (Wahyuning & Atiko, 2022). Noise parameter optimization shows that the noise levels (89.3569 dB, 77.9289 dB, and 78.5003 dB) remain within the noise regulation threshold (Kep.51/Men/1999, 1999), indicating that they still meet the standards. Moreover, noise parameters are necessary for assessing and determining ideal limits, thereby minimizing the risk of injury as early as possible, as stipulated in one of the clauses of ISO 11228-3 (International Organization for Standardization, 2007). Optimization of flow-direction parameters indicates that the right-to-left flow direction is optimal. These results suggest that the direction of material movement, which is more sensitive to handling, is from right to left. This is because, according to de Kovel et al. (2019), the majority of the world's population uses the right hand for manual activities that require extraordinary precision and expertise. Approximately 10% of the population is left-handed, and only about 1% can use both hands equally well (Andersen & Siebner, 2018).

Conclusions

This study aims to determine the optimal parameters of speed, noise, and direction of material flow on physical and mental workload in packaging work. The results show that the optimal combination of parameters for the physical workload is a speed of 25.8579 cm/s and a noise level of 89.3569 dB, with the optimal flow direction from the right. Meanwhile, the optimal parameters for mental workload are a speed of 25.8579 cm/s and a noise level of 77.9289 dB, with the optimal flow direction from the right. Further research is recommended to examine variability in lighting and vibration levels. This is because, in the real system, this condition becomes a disturbing factor.

Acknowledgments

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