Evaluation of E2 Mode Configuration on Komatsu HD785-7 Dump Trucks for Improving Fuel Efficiency in Downhill Haulage Operations

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ABSTRACT

Fuel consumption by dump trucks is a major contributor to operating costs and emissions in open-pit mining. This study evaluates the change in hourly fuel consumption associated with implementing E2 Mode on Komatsu HD785-7 dump trucks assigned to haul routes dominated by loaded-downhill travel at a mining contractor in East Kalimantan, Indonesia. A quantitative before-and-after quasi-experimental design was used. The study included the entire population of 24 trucks through total sampling. The pre-implementation period covered Month 1–Month 3 under E3 Mode, whereas the post-implementation period covered Month 4–Month 12 under E2 Mode. One operating-mode average was calculated for each truck, producing 24 paired fuel-consumption observations. The paired differences were analyzed using the Shapiro–Wilk test and a two-tailed paired-samples t-test at a 5% significance level. Average fuel consumption decreased from 68.0 to 60.0 L/h, a reduction of 8.0 L/h or 11.76%, $t(23) = -28.132$, $p < 0.001$, 95% CI [−8.588, −7.412]. Descriptively, productivity increased from 333 to 338 BCM/h, while cycle time changed only slightly from 18.302 to 18.403 min/cycle. Payload, haul distance, average speed, and average monthly operating hours per truck also remained broadly comparable. Because inferential tests were not available for these operational indicators and the study had unequal periods with no concurrent control group, the result should be interpreted as a strong association under the evaluated conditions rather than definitive causal evidence.

Keywords: *E2 Mode, fuel efficiency, Komatsu HD785-7, downhill haulage, mining dump truck.*

INTRODUCTION

Open-pit mining operations face increasing pressure to maintain productivity while reducing energy consumption, operating costs, and greenhouse gas emissions. Diesel-powered haul trucks are among the largest energy consumers in surface mining because they operate continuously under heavy payloads and varying haul-road conditions. Mining trucks are estimated to consume approximately 30–50% of a mine's total energy and may contribute more than 50% of its operational emissions [1]. In addition, fuel costs for open-pit mine trucks can account for up to 22% of total operating costs [2]. Improving haul-truck fuel efficiency is therefore an important strategy for reducing production costs and environmental impacts without requiring immediate replacement of existing diesel fleets.

Haul-truck fuel consumption is influenced by payload, haul distance, elevation change, road gradient, rolling resistance, speed, operating time, operator behavior, and engine configuration. Wang et al. analyzed 5,179 haulage cycles involving three mining-truck types and identified nonlinear relationships between fuel consumption, haul distance, elevation, and cycle operating time [2]. Road gradient is especially important because loaded uphill travel requires substantial engine power, whereas loaded downhill travel requires less traction and relies more heavily on the transmission and retarding system. Previous studies have confirmed that road slope and gross vehicle weight significantly influence truck fuel consumption [3], while improvements in the operating environment and haul-road condition may reduce fuel consumption by nearly 20%, depending on the vehicle type [4]. Consequently, operating a truck at a higher engine-power setting than required on predominantly downhill routes may result in unnecessary fuel consumption.

The Komatsu HD785-7 is equipped with a Variable Horsepower Control system that allows engine output to be adjusted according to operating requirements. Power Mode provides higher engine power for demanding conditions, particularly loaded uphill travel, while Economy Mode limits maximum horsepower while maintaining sufficient power for normal operation [5]. At the study site, approximately 30% of the haul-road segments had gradients steeper than −8%, and loaded travel consisted of approximately 85% downhill and 15% uphill movement. Before the intervention, the trucks operated using the E3 configuration and recorded an average fuel consumption of 68 L/h, exceeding the company target of 64 L/h.

Previous studies have mainly investigated payload, haul distance, road gradient, rolling resistance, fleet configuration, production scenarios, and predictive models of mining-truck fuel consumption [2]–[4],

[6]–[10]. These studies provide a strong basis for understanding external and operational determinants of fuel use, but field-based evidence on equipment-level optimization through route-specific engine-mode selection remains limited. In particular, there is little empirical evidence comparing E3 and E2 configurations on Komatsu HD785-7 trucks assigned to loaded-downhill routes. This study addresses that gap using long-term operational records from the same 24 trucks before and after the mode change. Its contribution is therefore a field-based estimate of the fuel-consumption difference associated with context-based equipment configuration, while explicitly recognizing the limitations of a nonrandomized before-and-after design.

Accordingly, this study aims to evaluate whether implementation of E2 Mode is associated with lower hourly fuel consumption than E3 Mode on Komatsu HD785-7 dump trucks operating on predominantly loaded-downhill haul routes. It addresses two questions: whether the paired difference in average fuel consumption is statistically significant and the magnitude of the observed fuel-consumption reduction. The null hypothesis (H0) states that the mean paired difference in fuel consumption between E2 and E3 Modes is zero, whereas the alternative hypothesis (H1) states that the mean paired difference is not zero. Operational indicators, including payload, cycle time, productivity, haul distance, gradient, speed, and road condition, were reviewed to support interpretation but were not treated as experimentally controlled variables.

LITERATURE REVIEW AND THEORETICAL FOUNDATION

Fuel efficiency in mining dump trucks refers to the ability of equipment to achieve the required haulage output with the lowest practicable fuel consumption. It can be expressed as hourly fuel consumption (L/h), fuel per cycle (L/cycle), or specific fuel consumption relative to production output (L/ton or L/BCM). In this study, the independent variable is the operating-mode configuration, represented by the transition from E3 Mode to E2 Mode, and the dependent variable is average hourly fuel consumption. Productivity, cycle time, payload, haul distance, average speed, and average monthly operating hours per truck were summarized descriptively as contextual indicators of operational comparability. Inferential testing was limited to fuel consumption because paired unit-level data for the other indicators were not available.

The relationship between operating-mode configuration and fuel consumption can be explained using vehicle power-demand principles and the Variable Horsepower Control concept. The power required by a dump truck depends on total resistance, vehicle speed, gross vehicle weight, and haul-road conditions. Loaded uphill travel requires greater traction power to overcome gradient resistance, whereas loaded downhill travel requires less engine traction because gravity assists vehicle movement and speed control relies more heavily on the transmission and retarding system. The Komatsu HD785-7 provides Power and Economy settings to align available engine output with operating demand [5]. The site-specific E2 and E3 configurations evaluated here represent different economy-setting levels applied by the operation. Their use must remain consistent with the applicable OEM guidance, equipment condition, retarder capacity, speed limits, and site safety controls.

The operating configuration reference used at the site distinguishes three fuel-saving settings according to engine output and load condition. E1 is the standard specification: loaded Power Mode provides 1,217 PS in F1–F7 and RL–RH, empty Power Mode provides 1,100 PS, and Economy Mode provides 1,020 PS. E2 is the principal fuel-saving setting: loaded Power Mode is limited to 1,100 PS in F1–F3 and 1,020 PS in F4–F7, empty Power Mode is limited to 950 PS, and reverse ranges retain 1,217 PS; Economy Mode remains at 1,020 PS. E3 is fuel saving with power-up: it retains 1,217 PS in loaded F1–F3 for stronger acceleration, while using the same 1,020 PS in loaded F4–F7 and 950 PS when empty as E2. Thus, the main E2–E3 distinction is loaded low-gear output. On loaded-downhill routes, E2 can reduce unnecessary available power because gravity assists travel and the retarding system controls speed, whereas E3 is preferable when loaded starts or uphill sections require additional low-gear power. Selection must remain consistent with OEM limits, retarder capacity, gradient, speed control, payload, and site safety procedures.

Three previous studies provide empirical foundations for understanding the determinants of haul-truck fuel consumption. First, Wang et al. analyzed 5,179 haulage cycles involving three mining-truck types and identified nonlinear relationships between fuel consumption, payload, haul distance, elevation change, and cycle operating time; their XGBoost model achieved an R^2 value of 0.93 [2]. Second, Posada-Henao et al. demonstrated that road gradient and gross vehicle weight significantly affected truck fuel consumption,

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indicating that consumption models should distinguish between different payload and gradient conditions [3]. Third, Bodziony and Patyk found that the operating environment affected energy consumption and truck reliability and reported that improving haul-road conditions could reduce fuel consumption by nearly 20%, depending on the vehicle type [4]. These studies support the relationship between operating conditions and fuel consumption but differ in emphasis: Wang et al. examined multidimensional consumption patterns, Posada-Henao et al. focused on road gradient and vehicle weight, and Bodziony and Patyk emphasized the technical condition of the operating environment.

Despite these findings, previous research has primarily focused on predictive modeling, simulation, haul-road conditions, payload, and route characteristics. Research specifically comparing different Economy Mode levels, particularly the change from E3 to E2 Mode on Komatsu HD785-7 dump trucks, remains limited. Existing studies also provide insufficient field-based evidence regarding whether a lower engine-power configuration can reduce fuel consumption under predominantly loaded-downhill conditions without adversely affecting cycle time and productivity. This limitation indicates the need for a quantitative field study using a before-and-after intervention design, actual fuel-consumption records, and operational controls for payload, haul distance, road conditions, observation period, and production intensity.

The conceptual framework positions the transition from E3 to E2 Mode as an equipment-configuration intervention expected to reduce unnecessary engine-power demand on loaded-downhill routes. The analysis compares each truck's average hourly fuel consumption under E3 Mode with the average for the same truck under E2 Mode. Route characteristics and operational conditions provide interpretive context rather than complete experimental control. The proposed relationship is E2 Mode configuration → lower maximum engine-power demand → lower average hourly fuel consumption. The hypothesis tested in this study is therefore limited to a difference in fuel consumption between the two observed configurations.

RESEARCH METHODOLOGY

This study employed a quantitative quasi-experimental approach with a before-and-after paired design to evaluate the effect of E2 Mode configuration on the hourly fuel consumption of Komatsu HD785-7 dump trucks. The study was conducted at a mining contractor's operation in East Kalimantan, Indonesia, on haul routes dominated by loaded-downhill travel. The pre-intervention period covered Month 1–Month 3, during which the trucks operated under E3 Mode, while the post-intervention period covered Month 4–Month 12 following the implementation of E2 Mode. The independent variable was the engine operating-mode configuration, consisting of E3 and E2 Modes, whereas the dependent variable was average hourly fuel consumption expressed in liters per operating hour (L/h).

The study population consisted of all 24 Komatsu HD785-7 dump trucks operating in the designated pit. Because every unit was included, a census or total-sampling technique was employed. The same trucks were evaluated in both periods, resulting in 24 paired observations, with the individual truck as the unit of analysis. Daily or shift-level records were aggregated into one average fuel-consumption value per truck for each mode so that the longer post-intervention period did not create more statistical observations than the pre-intervention period. Nevertheless, the three-month E3 period and nine-month E2 period had different exposure durations, which may have introduced seasonal and operational variation and is treated as a study limitation.

Table 1. Characteristics of the Research Design

Component	Description
Research design	Before-and-after quasi-experimental study
Study location	Mining contractor's operation in East Kalimantan
Population and sample	Entire population of 24 Komatsu HD785-7 trucks
Sampling technique	Census or total sampling
Pre-intervention	E3 Mode, Month 1–Month 3
Post-intervention	E2 Mode, Month 4–Month 12
Unit of analysis	Individual truck

Component	Description
Number of paired observations	24 pairs
Dependent variable	Average fuel consumption (L/h)
Statistical software	Minitab 17

Secondary quantitative data were collected from the company's fuel-control records, equipment hour-meter records, production reports, the equipment-monitoring database, and the site engine-mode configuration reference. A structured operational-data sheet was used to extract truck identification, date and shift, observation period, engine mode, diesel consumed, valid operating hours, payload, production, cycle time, haul distance, road gradient, average speed, road condition, and relevant operational delays. Hourly fuel consumption was calculated using Equation (1):

$$FC = \frac{F}{OH} \quad (1)$$

where FC is hourly fuel consumption (L/h), F is the total valid diesel consumption (L), and OH is valid operating time (h). Data were included only when truck identification, engine mode, fuel consumption, and operating hours were complete and traceable. Records associated with maintenance testing, nonproduction activities, abnormal refueling transactions, operations outside the designated pit, and invalid or duplicated entries were excluded.

Data validity was established by reconciling fuel transactions with hour-meter readings, dispatch records, and production reports. Measurement reliability was supported by standardized company procedures, scheduled calibration of fuel-measuring instruments, consistent data definitions, and cross-checking among databases. Aggregate productivity, cycle time, payload, haul distance, average speed, and average monthly operating hours per truck were reviewed descriptively as contextual indicators. Operating hours were normalized as the mean operating hours per truck per month so that the three-month E3 period and nine-month E2 period could be compared on the same monthly basis. These indicators were not randomized or held constant experimentally, and paired unit-level values were unavailable for inferential testing. Consequently, the mode change was the principal recorded intervention, but other time-varying factors cannot be fully excluded as alternative explanations. Cronbach's alpha was not applicable because the study used equipment-generated measurements rather than a multi-item questionnaire.

Statistical analysis was performed using Minitab 17. Descriptive statistics included the mean, standard deviation, minimum, maximum, absolute difference, and percentage reduction in fuel consumption. Paired differences were defined as Di = FCE2,i − FCE3,i. Normality was evaluated for the 24 paired differences using the Shapiro–Wilk test. Because the differences were approximately normally distributed, a two-tailed paired-samples t-test was conducted at $\alpha = 0.05$. The null hypothesis specified a mean paired difference of zero, and it was rejected when $p < 0.05$. A two-sided 95% confidence interval and Cohen's dz were reported to describe the precision and standardized magnitude of the observed difference. Statistical inference describes consistency across the 24 trucks; generalization beyond this fleet requires caution because the trucks constituted the full population in one designated pit. Percentage reduction was calculated using Equation (2):

$$R_{(FC)} = \left(\left(\overline{(FC)}_{(E3)} - \overline{(FC)}_{(E2)}\right) / \left(\overline{(FC)}_{(E3)}\right)\right) \times 100\% \quad (2)$$

RESEARCH FLOW

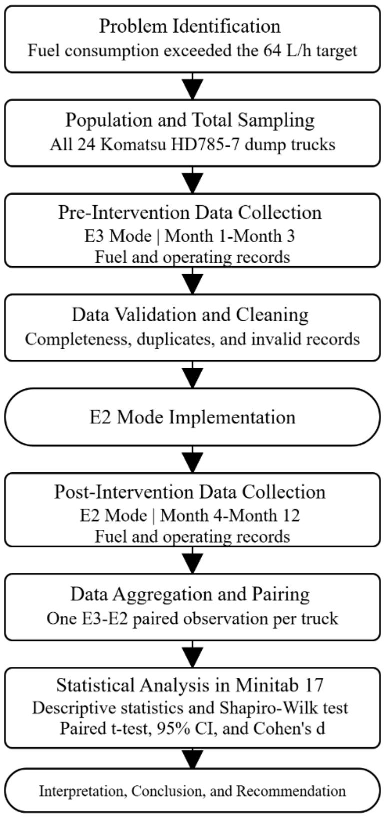

Figure 1. Research Flow for Evaluating E2 Mode Implementation on Komatsu HD785-7 Dump Trucks

RESULTS AND DISCUSSION

Discussion of Data I: Comparison of Fuel Consumption

The study evaluated all 24 Komatsu HD785-7 dump trucks operating in the designated pit. During Month 1–Month 3, the trucks used E3 Mode; during Month 4–Month 12, the same trucks used E2 Mode. The primary comparison was average hourly fuel consumption. Aggregate productivity, cycle time, payload, haul distance, average speed, and average monthly operating hours per truck were also compared descriptively to assess whether the two periods represented broadly similar operating intensity. Because paired unit-level observations for these indicators were not available, no p-values were calculated for them.

Table 2. Fuel-consumption performance before and after E2 Mode implementation

Data	Observation period	Mode configuration	Number of trucks	Average fuel consumption (L/h)	Difference from target (L/h)	Performance against target
1	Month 1–Month 3	E3 Mode	24	68	+4	6.25% above target
2	Month 4–Month 12	E2 Mode	24	60	−4	6.25% below target

Note: The operational fuel-consumption target was 64 L/h. Positive differences indicate fuel consumption above the target, whereas negative differences indicate consumption below the target. Source: Company operational database.

Table 3. Comparison of Operational Indicators under E3 and E2 Modes

Operational indicator	**E3 Mode**	**E2 Mode**	**Change**	**p-value**
Fuel consumption (L/h)	68.0	60.0	−11.76%	<0.001
Productivity (BCM/h)	333	338	+1.50%	Not tested
Cycle time (min/cycle)	18.302	18.403	+0.55%	Not tested

Average payload (ton)	96.7	97.6	+0.93%	Not tested
Haul distance (km)	3.161	3.260	+3.12%	Not tested
Average speed (km/h)	24.4	25.0	+2.46%	Not tested
Average monthly operating hours/truck (h/month)	435.305	436.207	+0.21%	Not tested

Note: Positive changes indicate an increase under E2 Mode. Haul-distance values supplied as 3,161.11 m and 3,259.9 m were converted to 3.161 and 3.260 km. The operating-hour values represent average operating hours per truck per month, not cumulative hours for the full three- and nine-month observation periods. Only fuel consumption was evaluated using paired inferential statistics; the remaining indicators are aggregate descriptive values. Source: Company operational database.

Table 3 shows that the 11.76% reduction in hourly fuel consumption occurred while aggregate operational indicators remained broadly stable. Productivity increased by 1.50%, average payload by 0.93%, average speed by 2.46%, and average monthly operating hours per truck by 0.21%. Cycle time increased slightly by 0.55%, while haul distance increased by 3.12%. These descriptive changes do not indicate a material reduction in operating intensity; however, statistical equivalence or significance cannot be concluded without paired truck-level observations for each indicator.

As presented in Table 2, average fuel consumption decreased from 68 L/h under E3 Mode to 60 L/h after E2 Mode implementation. The absolute reduction was 8 L/h. Before the intervention, average fuel consumption exceeded the operational target by 4 L/h. After the intervention, fuel consumption was 4 L/h below the target. This represents a shift of 8 L/h relative to the operational standard and indicates that the E2 configuration achieved better fuel performance than E3 Mode under the observed haulage conditions.

Applying Equation (2), the observed percentage reduction was:

$$R_{FC} = \frac{68 - 60}{68} \times 100\% = 11.76\% \quad (3)$$

The observed mean fuel consumption under E2 Mode was approximately 11.76% lower than under E3 Mode. At the fleet level, if all 24 trucks operated simultaneously for one valid operating hour, the potential hourly fuel saving was calculated using Equation (4):

$$FS_h = (FC_{E3} - FC_{E2}) \times N \quad (4)$$

where FSh represents potential hourly fleet fuel savings and N is the number of trucks. Accordingly:

$$FS_h = (68 - 60) \times 24 = 192 \text{ L/h} \quad (5)$$

The value of 192 L/h represents a theoretical fleet-level saving under simultaneous operation and comparable operating conditions. Total realized fuel savings must be calculated using the actual operating hours of each truck. Therefore, this value should not be multiplied by calendar hours without verifying valid equipment operating hours.

Discussion of Data II: Statistical Evaluation and Interpretation

Statistical analysis was conducted using paired observations from the same 24 Komatsu HD785-7 dump trucks. Each truck's average fuel consumption under E3 Mode during Month 1–Month 3 was paired with its average fuel consumption under E2 Mode during Month 4–Month 12. This paired design was selected because the same trucks were observed under both operating-mode configurations. Consequently, truck-specific characteristics that remained relatively constant, such as engine specification, rated capacity, and equipment model, were partially controlled through within-truck comparison.

Before conducting the paired-samples *t*-test, the normality of the paired differences was evaluated using the Shapiro–Wilk test. The test was applied to the differences between E2 and E3 fuel consumption rather than to each dataset separately. The result produced a Shapiro–Wilk statistic of W=0.972 and *p*-value of 0.726. Because the *p*-value was greater than the significance level of 0.05, there was insufficient evidence to reject the assumption of normality. Therefore, the paired differences were considered approximately normally distributed, and the paired-samples *t*-test was considered appropriate.

The descriptive analysis showed that average fuel consumption decreased from 68.000 ± 0.905 L/h under E3 Mode to 60.000 ± 1.218 L/h under E2 Mode. The mean paired difference (E2 minus E3) was −8.000 L/h, with a standard deviation of 1.393 L/h. Individual reductions ranged from 4.7 to 10.5 L/h, and all 24 trucks recorded lower consumption under E2 Mode. A two-tailed paired-samples t-test produced $t(23) = -28.132$, $p < 0.001$. The two-sided 95% confidence interval ranged from −8.588 to −7.412 L/h and remained entirely below zero. The null hypothesis was therefore rejected, supporting a difference in hourly fuel consumption between the observed configurations. Cohen's dz was −5.742; the sign indicates the direction of change, while the absolute value indicates a very large standardized difference relative to the variability of the paired truck-level changes. This large effect does not, however, remove potential bias from unequal periods or other time-varying operational conditions.

The observed pattern is consistent with Wang et al. [2], who found that mining-truck fuel consumption was associated with payload, haul distance, elevation change, and cycle operating time. It also aligns with Posada-Henao et al. [3], who demonstrated the importance of road gradient and gross vehicle weight, and Bodziony and Patyk [4], who linked the operating environment to haulage energy efficiency. At the study site, approximately 85% of loaded travel occurred under downhill conditions, for which traction-power demand would generally be lower. Under E2, loaded output was limited to 1,100 PS in F1–F3 and 1,020 PS in F4–F7, compared with the 1,217 PS available in F1–F3 under E3. The observed 8 L/h or 11.76% difference is therefore technically plausible as an outcome associated with lower available power during loaded low-gear operation, although the present design cannot attribute the entire difference exclusively to E2 Mode.

Beyond operational cost reduction, improved fuel efficiency contributes directly to greenhouse gas mitigation because diesel combustion remains one of the primary sources of emissions in surface mining operations [11], [12]. The observed reduction of 11.76% in average fuel consumption indicates that engine-mode optimization may support broader sustainability objectives by lowering fuel demand without requiring fleet replacement or major infrastructure modifications. Consequently, adaptive engine-mode selection can be considered a practical transition strategy for mining companies seeking incremental emission reductions while maintaining the use of existing diesel-powered haulage fleets [13].

The findings indicate that equipment configuration may complement operational measures such as payload management, road maintenance, and route optimization. On routes dominated by loaded-downhill travel, aligning the engine setting with actual traction demand may reduce unnecessary fuel use. This interpretation remains conditional because the study did not isolate the mode effect from all changes in route, weather, traffic, operator behavior, idle time, and production intensity.

From a practical perspective, E2 Mode may be considered for Komatsu HD785-7 trucks assigned to predominantly loaded-downhill routes after route-specific risk assessment and confirmation of compliance with OEM and site requirements. Implementation should include controlled truck allocation, operator guidance, retarder and speed monitoring, and routine review of fuel consumption, payload, cycle time, productivity, and equipment health. The findings should be interpreted cautiously because the study had no concurrent control group, used unequal three- and nine-month observation periods, and relied on aggregated truck-level averages. Seasonal conditions, rainfall, road maintenance, payload, haul distance, traffic density, operator behavior, idle time, equipment condition, and production intensity may have contributed to the observed difference.

CONCLUSION

Implementation of E2 Mode on 24 Komatsu HD785-7 dump trucks operating on predominantly loaded-downhill routes was associated with a decrease in average hourly fuel consumption from 68.0 L/h under E3 Mode to 60.0 L/h under E2 Mode, equivalent to 8.0 L/h or 11.76%. The paired difference was statistically significant, $t(23) = -28.132$, $p < 0.001$, with a two-sided 95% confidence interval from −8.588 to −7.412 L/h. Descriptively, productivity increased by 1.50%, from 333 to 338 BCM/h, while cycle time increased by only 0.55%, from 18.302 to 18.403 min/cycle. Payload, haul distance, speed, and average monthly operating hours per truck changed by less than approximately 3.2%. These aggregate indicators suggest broadly comparable operational performance, although statistical equivalence was not tested. Operational adoption should remain conditional on route assessment, OEM and site requirements, retarder and speed safety controls, operator guidance, and continuous monitoring of fuel and production performance.

Future research should use balanced pre- and post-intervention periods or a concurrent comparison fleet and report paired results for productivity, cycle time, payload, haul distance, speed, valid operating hours, idle time, road condition, and rainfall. Monthly trend analysis, operating-hour-weighted fuel consumption, and multivariable or mixed-effects models would help separate the engine-mode effect from seasonal, truck-specific, and operational variation. Integration with fleet-management-system data and emission indicators could further support adaptive, route-specific energy management in surface mining operations.

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