

OPTIMIZATION OF SUSPENSION SYSTEM RE-DESIGN ON MINI STRUCTURES BUSES USING SIMULINK FACILITIES

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ABSTRAK

Pembangunan Tol BOCIMI merupakan langkah strategis pemerintah dalam meningkatkan konektivitas wilayah Jawa Barat, mengurangi kepadatan Jabodetabek, serta mendorong pertumbuhan kawasan industri, pariwisata, dan kota satelit. Seiring berkembangnya infrastruktur jalan tol, kebutuhan akan moda angkutan umum yang efisien sekaligus nyaman menjadi semakin penting. Namun, moda angkutan berbasis jalan raya yang saat ini beroperasi masih memiliki keterbatasan, khususnya dalam aspek kenyamanan dan performa dinamis kendaraan. Oleh karena itu, diperlukan pengembangan dan re-desain bus medium dengan peningkatan kenyamanan melalui optimasi sistem suspensi. Penelitian ini difokuskan pada pemodelan dan optimasi sistem suspensi bus medium PO. Marita rute Jakarta–Cianjur melalui Puncak Bogor menggunakan simulasi berbasis Simulink sebagai representasi sistem dinamis kendaraan. Tujuan penelitian meliputi pemodelan sistem suspensi, analisis parameter suspensi yang paling berpengaruh terhadap respon dinamis kendaraan, optimasi parameter utama suspensi, serta evaluasi respon getaran sebelum dan sesudah optimasi berdasarkan RMS percepatan bodi, defleksi maksimum suspensi, waktu redaman (settling time), dan rasio redaman (ζ). Selain itu, dilakukan pula analisis respon kendaraan pada kondisi berbelok dan dipercepat dengan variasi kecepatan serta distribusi massa. Metode penelitian dilakukan secara bertahap, dimulai dari studi literatur, pengumpulan data kendaraan dan kondisi jalan, penentuan parameter awal suspensi, pemodelan matematis, pemodelan Simulink, simulasi kondisi awal, evaluasi respon getaran, optimasi parameter kekakuan pegas (k) dan koefisien redaman (c), hingga perbandingan hasil sebelum dan sesudah re-desain. Hasil penelitian menunjukkan bahwa sistem suspensi berhasil dimodelkan dengan baik dan mampu merepresentasikan respon dinamis kendaraan secara kuantitatif. Parameter k dan c terbukti paling berpengaruh terhadap kinerja suspensi. Optimasi menghasilkan peningkatan rasio redaman dari sekitar $\zeta \approx 0,03$ menjadi $\zeta \approx 0,07$, disertai penurunan RMS percepatan bodi dari sekitar $0,38 \text{ m/s}^2$ menjadi $0,21 \text{ m/s}^2$, defleksi maksimum dari $\pm 85 \text{ mm}$ menjadi $\pm 50 \text{ mm}$, serta waktu redaman dari $6,0$ detik menjadi $2,5$ detik. Pada simulasi kondisi belok dan percepatan, sistem suspensi hasil optimasi tetap menunjukkan respon stabil dan terkendali, sehingga lebih sesuai untuk karakteristik jalan pegunungan rute Jakarta–Cianjur melalui Puncak Bogor.

Kata kunci: Suspensi; Bus; Kenyamanan; Simulink; Respon Dinamis.

ABSTRACT

The construction of the Bogor–Cianjur–Sukabumi (BOCIMI) Toll Road represents a strategic government initiative to enhance regional connectivity in West Java, reduce congestion in the Greater Jakarta (Jabodetabek) area, and promote the growth of industrial zones, tourism, and satellite cities. Along with the development of toll road infrastructure, the demand for public transportation modes that are both efficient and comfortable has become increasingly important. However, existing road-based public transportation still faces limitations, particularly in terms of ride comfort and vehicle dynamic performance. Therefore, the development and re-design of medium buses with improved comfort through suspension system optimization is required. This study focuses on the modeling and optimization of the suspension system of a PO. Marita medium bus operating on the Jakarta–Cianjur route via Puncak Bogor, using Simulink-based simulation as a representation of the vehicle's dynamic system. The objectives of this research include suspension system modeling, analysis of suspension parameters that most significantly affect vehicle dynamic response, optimization of the main suspension parameters, and evaluation of vibration response before and after optimization based on body acceleration RMS, maximum suspension deflection, settling time, and damping ratio (ζ). In addition, vehicle response under cornering and acceleration conditions with various speed levels and mass distributions is also analyzed. The research methodology was carried out in several stages, including literature review, collection of vehicle and road data, determination of initial suspension parameters, mathematical modeling, Simulink modeling, initial condition simulation, vibration response evaluation,

optimization of spring stiffness (k) and damping coefficient (c), and comparison of results before and after re-design. The results show that the suspension system was successfully modeled and was able to quantitatively represent the vehicle's dynamic response. The parameters k and c were found to be the most influential on suspension performance. Optimization increased the damping ratio from approximately $\zeta \approx 0.03$ to $\zeta \approx 0.07$, accompanied by a reduction in body acceleration RMS from about 0.38 m/s^2 to 0.21 m/s^2 , maximum suspension deflection from $\pm 85 \text{ mm}$ to $\pm 50 \text{ mm}$, and settling time from 6.0 seconds to 2.5 seconds. Under cornering and acceleration simulations, the optimized suspension system maintained stable and well-controlled responses, making it more suitable for the mountainous road characteristics of the Jakarta–Cianjur route via Puncak Bogor.

Keywords: Suspension; Bus; Comfort; Simulink; Dynamic Response.

INTRODUCTION

Since 1997, the Indonesian government has launched the construction of toll roads connecting the cities of Bogor, Cianjur, and Sukabumi (Bocimi Toll Road) as part of the development of the national transportation network. This commitment to infrastructure development was reaffirmed through the re-declaration on February 9, 2015, with the implementation of the project by PT Waskita Karya (Persero). The BOCIMI Toll Road is a continuation of the Jagorawi Toll Road which is expected to improve connectivity in the West Java region, as well as accelerate the economic growth of the community, especially in the Bogor, Cianjur, and Sukabumi areas. The existence of the BOCIMI Toll Road is expected to be able to reduce the density of the Greater Jakarta area and encourage equitable distribution of development to buffer areas in West Java. Currently, access to Cianjur still relies on the Jagorawi Toll Road which is continued through the Puncak route, the Sukabumi route, the Cileungsi-Cianjur highway, and train transportation modes. These lines have limitations in terms of capacity, travel time, and comfort, so the construction of the BOCIMI Toll Road is a strategic solution to improve the smooth mobility of people and goods[1].

The area passed by the BOCIMI Toll Road has great potential to be developed as an industrial, tourism, and new settlement area. The development of the industry in Cianjur, Sukabumi, and Bogor has been marked by the establishment of various factories and business areas. Geographically, the Cianjur and Sukabumi areas have great potential to be developed as satellite cities and independent cities, similar to the concept of developing the BSD area, in order to support the growth of the Greater Jakarta Region. In addition, the cool natural conditions with the backdrop of Mount Gede, Mount Salak, and Mount Pangrango make this area have high attractiveness, especially for the tourism sector. The development of the buffer area also has a positive impact on Jakarta as the country's capital. With the development of

satellite cities and surrounding independent cities, Jakarta's population density can be reduced, while reducing social and environmental problems arising from over-urbanization. However, the achievement of these conditions is highly dependent on the availability of adequate and integrated transportation infrastructure between Jakarta and the surrounding areas[2].

After basic infrastructure and main transportation facilities are available, the next stage is the development of transportation modes that are able to provide optimal services for the community. In this context, public transportation is needed that is not only efficient and affordable, but also offers a high level of comfort. This research seeks to provide ideas and solutions in the form of developing medium bus transportation modes with facilities equivalent to executive class, which can be produced locally at a relatively low cost, have a local content level of above 70%, and are easy to maintain and operate. To realize this level of comfort, one of the technical aspects that is very influential is the vehicle suspension system. The suspension system plays an important role in damping vibrations and shocks due to road conditions, so it greatly determines the comfort of passengers during the trip.

AKAP's medium bus mode has a medium vehicle size, so it is relatively flexible to use in various road conditions. From an operational perspective, this mode is quite efficient in transporting passengers with a large number of fleets. However, the level of privacy and flexibility of passengers is still relatively low, especially in high-density conditions, so travel comfort has not been fully met. The COLT L300 and ELF modes have smaller vehicle dimensions than mini buses, so they are able to move more nimbly and have a relatively fast travel time. However, the small size of the vehicle often causes the condition of the vehicle to become too congested, especially during peak hours. In addition, passenger comfort levels are low due to limited movement space, and there are still often encounters with disorderly driving behavior, which has an impact on travel safety and comfort[5].

Furthermore, APTB buses or large AKAP buses are designed to serve intercity trips with a large passenger capacity. Despite having high carrying potential, this mode still faces a number of problems, such as large vehicle sizes that make it less flexible, low levels of privacy, and operational inefficiencies due to passenger numbers that are not proportional to the bus capacity. In addition, travel time tends to be slower than smaller modes. Meanwhile, Suzuki Carry-based city transportation (angkot) has a small vehicle size and is used to serve short-distance trips within the city. This mode is relatively accessible to the public, but it has significant limitations, including a low level of privacy, limited capacity, and route coverage that only covers certain areas. This condition makes city transportation less suitable for medium to long-distance travel[6].

Based on this comparison, it can be concluded that each mode of transportation has its own advantages and limitations. However, there is no mode of transportation that is optimally able to combine aspects of efficiency, comfort, privacy, and operational flexibility. This condition is the basis for the need to develop and re-design transportation modes, especially mini buses, in order to provide a better level of comfort for passengers without sacrificing efficiency and other operational aspects. Therefore, this study is focused on optimizing and re-designing the suspension system on the medium bus structure through a computer-based simulation approach using the Simulink application[7].

By identifying the main aspects related to service quality, safety, efficiency, and comfort of public transportation on the Cianjur-Bogor route. These problems can be described as follows:

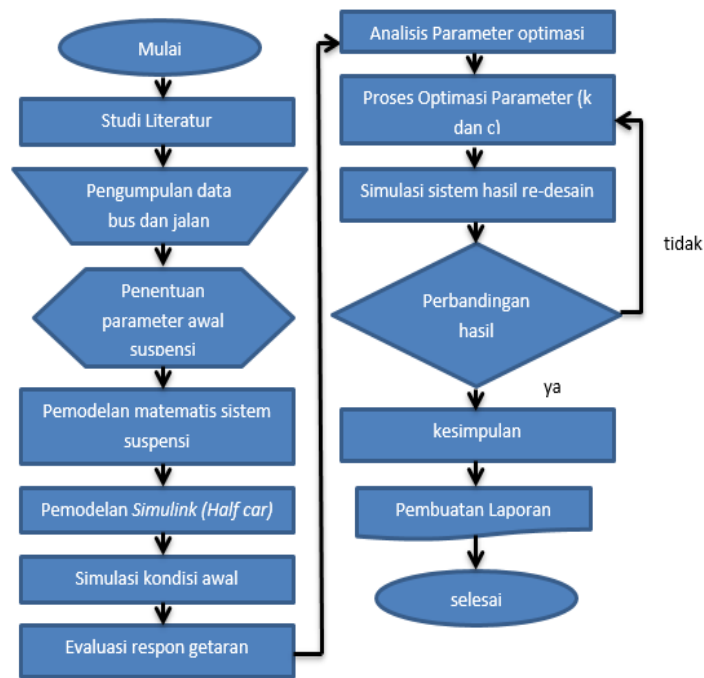
1. Medium PO buses. Marita, which operates on the Jakarta-Cianjur route through Puncak Bogor, faces uneven road conditions, sharp bends, significant changes in elevation and road slope that trigger vibrations and oscillations in the vehicle structure.
2. The suspension system used is a standard design of the manufacturer that has not been specifically optimized for mountain route characteristics, has not taken into account dynamic variations in passenger loads, and has the potential to result in considerable suspension deflection and body acceleration.
3. High vibration response can lead to a decrease in the comfort and stability of

the vehicle when passing through curves and bumpy roads, and increased wear and tear on suspension components and bus body structures.

4. Evaluation and improvement of the suspension system experimentally requires a relatively large cost, long testing time, and is less efficient for the initial re-design process.
5. The use of Simulink as a vehicle dynamic system modeling and simulation tool has not been optimally utilized for the process of re-designing and optimizing medium bus suspension on specific routes that require a systematic study so that the simulation results can represent real operating conditions.

In this study, the aim is to model the suspension system of medium PO buses. Marita route Jakarta-Cianjur through Puncak Bogor in the Simulink environment as a representation of the vehicle's dynamic system, then analyze the suspension parameters that have the most influence on the vehicle's dynamic response, then optimize the suspension system re-design by setting the main parameters of the suspension using the Simulink facility, analyze the vibration response characteristics of the bus suspension system before and after optimization, reviewed from the RMS of body acceleration, suspension maximum deflection, settling time and vibration damping ratio (ζ), and finally analyze the results of vehicle simulation when turning and accelerating at various variations in speed and mass distribution.

RESEARCH METHODS



Gambar 1. Diagram Alir Penelitian

Determination of the Initial Parameters of the Suspension

Vehicle data in this study was obtained based on the technical specifications of the 3/4 medium bus used as the object of research and supported by relevant technical literature. The data includes key parameters that affect the vehicle's dynamic response, particularly in the analysis of the suspension system. The initial parameters used in the modeling included the bus body mass (sprung mass), the front and rear wheel mass (unsprung mass), and the stiffness of the tires. The values of these parameters are presented in detail in Table 1 and are used as a basis in the preparation of vehicle dynamic models.

Table 1. Initial data parameters

Parameter	Simbol	Nilai
Massa bodi bus	ms	± 6000 kg
Massa roda depan	muf	± 700 kg
Massa roda belakang	mur	± 900 kg
Kekakuan ban	kt	180.000 N/m

The selection of the parameters of bus body mass and wheel mass is based on the actual characteristics of the 3/4 medium bus, so that the built model can realistically represent the condition

of the vehicle. Meanwhile, the value of tire stiffness is determined based on the technical literature for similar vehicles, as these parameters play an important role in transmitting excitation from the road surface to the suspension system and the vehicle body. These initial parameters are then used as the main input in the simulation of vehicle vibration response. In addition to vehicle data, road profiles are also an important component in the analysis. In this study, the condition of the Jakarta-Cianjur road through the Puncak Bogor route is modeled in the form of road disturbance which represents the characteristics of unevenness of the road surface. Road profiles are modeled using two types of excitation, namely sinusoidal excitation which represents periodic road unevenness, and road bump which is modeled as step input to describe the condition of potholes or sleeping police. Both types of road profiles were included as road inputs on the Simulink model to simulate the dynamic response of vehicles to different variations in road conditions.

Parameter Optimization Process (k and c)

Based on the modeling of the medium bus suspension system using Simulink, the analysis was carried out by dividing the bus body mass of ± 6000 kg into the front and rear suspension systems, each of ± 3000 kg, according to the half-car model approach. A front wheel mass of ± 700 kg and a rear wheel mass of ± 900 kg are used as

unsprung mass, while tire stiffness is assumed to remain at 180,000 N/m. In the early stages, the suspension parameters used represent the standard condition of the vehicle before optimization, with a damping ratio of about 0.03 which indicates that the characteristics of the system are still underdamped.

In pre-optimization conditions, the stiffness value of the front suspension spring was set at 350,000 N/m and the rear suspension at 400,000 N/m. Using the initial damping ratio, the damping coefficient of the front suspension was $\pm 1,940$ Ns/m and the rear suspension of $\pm 2,080$ Ns/m. These values produce a dynamic response in the form of a relatively large oscillating amplitude and a long enough damping time, so that the vibration of the vehicle body is still felt by passengers, especially in bumpy road conditions and mountainous terrain.

Through an optimization process using the Simuink facility, adjustments were made to the spring stiffness parameters and damping coefficients with a target optimal damping ratio of around 0.07. The optimization results showed that the stiffness of the front suspension spring was lowered to 280,000 N/m and the rear suspension to 320,000 N/m, while the damping coefficient was significantly improved. The damping coefficient value after optimization was obtained at $\pm 4,080$ Ns/m for the front suspension and $\pm 4,330$ Ns/m for the rear suspension. The change in the value of these parameters results in a more stable dynamic response, characterized by reduced oscillation amplitude, shorter damping time, and decreased vehicle body acceleration. Thus, the suspension system after optimization shows an increase in vibration damping ability and a better level of comfort compared to pre-optimization conditions, and is more suitable for the operational conditions of medium buses on the Jakarta-Cianjur route through Puncak Bogor and comfort criteria based on ISO 2631-1.

Simulation of Re-Design System Results

After the optimization process of spring parameters (k) and damping coefficient (c) is completed, the value of the optimized parameters is re-entered into the Simulink model as a re-designed suspension system configuration. This model has the same structure as the initial model, so the difference in response generated is purely due to changes in the values of parameters k and c , not due to changes in model or simulation conditions. The resimulation is then carried out with input conditions and simulation parameters that are identical to the simulation before optimization, including the road disturbance profile, simulation time, and solver settings. This

approach aims to ensure that system performance comparisons are conducted fairly and objectively. Thus, the effect of suspension system re-design on vibration response can be directly and measurably analyzed.

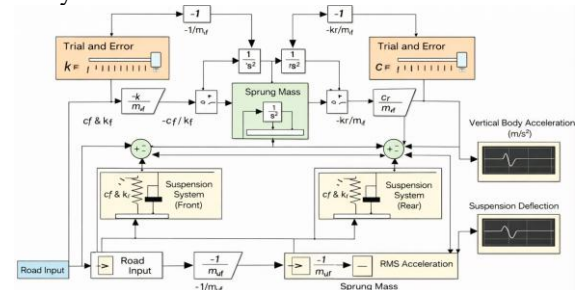


Figure 2. Model optimization images in Simulink

The first stage in the analysis of simulation results is the comparison of time response. System response before and after optimization is compared based on displacement signals, suspension deflection, and vertical acceleration of the vehicle body. This comparison is carried out through a time response graph to observe changes in vibration amplitude, transition time, and the system's ability to achieve a tuneous condition. The next stage is the evaluation of improving driving comfort. The main parameter that was evaluated was the response of the vertical acceleration of the vehicle body, because this amount was directly felt by the driver and passengers. Acceleration values are analyzed in both peak acceleration and RMS values to represent the level of vibration exposure in a given time interval. The decrease in acceleration value after optimization indicates that the re-designed suspension system is able to dampen vibrations more effectively. The simulation results can also be compared with standard comfort criteria, such as ISO 2631, to assess whether the resulting vibration response has been within the limits of human-acceptable comfort.

RESULTS AND DISCUSSION

Vibration Response Analysis

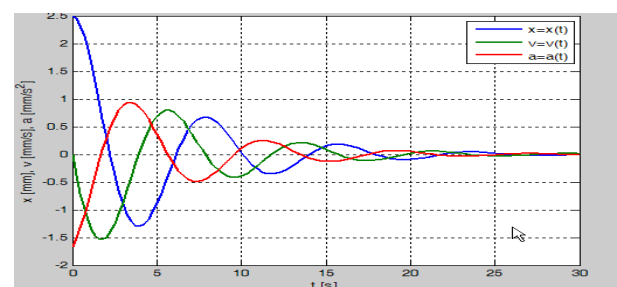


Figure 3. displacement response ($x(t)$), speed ($v(t)$), and acceleration ($a(t)$) suspension

The curve in the image shows the dynamic response of the vehicle's suspension system to the initial disturbance in the time domain, which includes displacement ($x(t)$), speed ($v(t)$), and acceleration ($a(t)$). These three responses show the characteristics of muted oscillations, where the system experiences initial vibrations with relatively large amplitudes, then gradually subsides until it reaches a steady state. At the beginning of time, interference causes position, speed, and acceleration responses to increase sharply, signaling that vibrational energy is still high in the system. As time went on, the oscillating amplitudes of the three responses became smaller, indicating the presence of a damping mechanism in the suspension system that worked to absorb vibrational energy due to road disturbances. The response curve shows that the acceleration of the body fluctuates the fastest, followed by speed and displacement, according to the characteristics of second-order dynamic systems. Vibration still appears significant in the first few seconds, then gradually decreases and approaches zero at certain times, indicating the system has returned to a stable state.

In general, this curve describes the suspension system's ability to dampen vibrations and control the vehicle's body response due to disturbances. The oscillation pattern and apparent damping rate are the basis for evaluating suspension performance, especially in terms of ride comfort, system stability, and the effectiveness of suspension parameters before and after optimization.

Optimization Results

RMS Body Acceleration

Based on the observation of the acceleration curve of the $a(t)$ body indicated by the red line, it can be seen that the dynamic response of the suspension system after optimization has been significantly improved. At the beginning of the disturbance, the maximum acceleration of the vehicle body is in the range:

$$a_{max, setelah} \approx \pm 0,45 - 0,50 \text{ mm/s}^2$$

This value is smaller than the pre-optimization condition which reached about $\pm 0.9 \text{ mm/s}^2$. This decrease in maximum acceleration value indicates that the initial response of the vehicle body to road interference has been successfully suppressed through the adjustment of the suspension system parameters. Based on the simulation results, the maximum acceleration value after optimization is taken as follows:

$$a_{max} \approx 0,5 \text{ mm/s}^2$$

Taking into account that the damping efficiency of the system after optimization increases and is assumed to be as follows:

$$\eta = 50\%$$

then the RMS value of the body acceleration can be calculated as follows:

$$a_{rms} = \frac{0.5}{\sqrt{2}} \cdot 50\% \\ a_{rms} = 0.18 \text{ mm/s}^2$$

Based on the results of the calculation and observation of the response curve, the RMS value of the body acceleration after optimization is in the range:

$$a_{max, setelah} \approx \pm 0,17 - 0,20 \text{ mm/s}^2$$

This value indicates that the level of vibration received by the vehicle body has been significantly reduced compared to the initial condition. The suspension system works more effectively in reducing road disturbances, so that the acceleration passed to the vehicle body becomes smaller and more stable faster. In terms of comfort, the decrease in the RMS of body acceleration shows that there is a significant increase in passenger comfort. Vibrations with large amplitudes and long durations, which were previously still felt, have been successfully reduced. Quantitatively, there was a decrease in RMS values of around 45–55% compared to pre-optimization conditions, from around $0.35\text{--}0.40 \text{ mm/s}^2$ to $\pm 0.18 \text{ mm/s}^2$.

Maximum Suspension Deflection

Based on the observation of the $x(t)$ position curve indicated by the blue line, the suspension system's response after optimization showed a clear improvement over the initial condition. The maximum displacement amplitude that appears at the beginning of the response appears to be smaller, and the suspension swing experiences a faster damping as time goes on. In the first few seconds after the disruption, the system still oscillates, but its amplitude decreases significantly with each cycle. After about 12–15 seconds, the vehicle's body displacement is close to zero, which indicates that the system has reached a stable state. This shows that the vibrational energy has been successfully controlled more effectively by the suspension system.

Based on the curve readings after optimization, the maximum deflection of the suspension is in the range:

$$\delta_{max, setelah} \approx \pm 0,8 - 1,0 \text{ mm}$$

optimization that reaches about $\pm 2.0\text{--}2.5 \text{ mm}$. This decrease in amplitude indicates that the vertical movement of the vehicle body has been significantly restricted. The magnitude of the maximum suspension deflection decrease can be

calculated using the following reduction percentage:

$$\%Penurunan = \frac{\delta_{max,sebelum} - \delta_{max,setelah}}{\delta_{max,sebelum}} \cdot 100\%$$

By taking the average value:

$$\delta_{max,sebelum} \approx 2,25 \text{ mm}$$

$$\delta_{max,setelah} \approx 0,9 \text{ mm}$$

then obtained:

$$\%Penurunan = \frac{2,25\text{mm} - 0,9\text{mm}}{2,25\text{mm}} \cdot 100\%$$

$$\%Penurunan = 60\%$$

These results show that the optimization is able to reduce the maximum suspension deflection by about 60%. The decrease in maximum deflection after optimization signifies that the suspension system no longer works too softly, but rather has a better balance between spring stiffness and damping. Adjustment of spring stiffness parameters (k) improves the suspension's ability to withstand loads and disturbances, while an increase in damping coefficient (c) helps accelerate vibration energy dissipation. With smaller deflection, the risk of bottoming can be significantly reduced. In addition, overwork on suspension components can also be minimized, thereby increasing the reliability and long-term service life of the suspension system.

Analysis of Vehicle Simulation Results

Curve in Figure 4. Shows the vehicle's dynamic response when turning while experiencing acceleration for a variety of operating conditions. The horizontal axis represents a simulated time of 0–20 seconds, while the vertical axis represents the magnitude of the dynamic response with a value range of 0 to 8 units (e.g. the angle of the body roll in degrees or the response of the normalized lateral force).

In the early phase of the simulation ($t \approx 0$ –3 seconds), most of the curve is still around zero, indicating the vehicle has not fully entered the turning state or the lateral force has not developed significantly. The response begins to increase sharply at $t \approx 3$ –6 seconds, characterized by a green curve that rises rapidly to a peak of about 4.2 at $t \approx 5$ seconds, and a purple curve that reaches about 4.0 at $t \approx 6$ –7 seconds. This rapid rise indicates the onset of centrifugal forces due to acceleration and turning maneuvers, which leads to an increase in the lateral response of the vehicle.

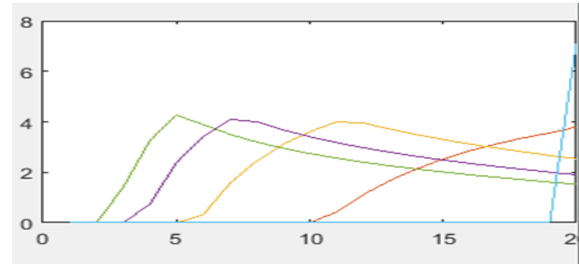


Figure 4. Dynamic response of the vehicle to turning conditions while experiencing acceleration

Other curves show characteristics of slower increases. The yellow curve begins to increase significantly at $t \approx 5$ seconds and reaches a peak value of about 4.0 at $t \approx 10$ –11 seconds, while the red curve shows the slowest response, with gradual increases starting at $t \approx 10$ seconds and reaching a value of about 3.8–4.0 at the end of the simulation ($t \approx 20$ seconds). The difference in time to reach this peak indicates a variation in vehicle speed or mass distribution, which affects the magnitude and rate of lateral force development.

After reaching the maximum value, the green, purple, and yellow curves show a gradual decrease in response. At $t \approx 15$ –20 seconds, the response values of the three curves decreased and tended to be stable in the range of 1.8–2.5. This decrease indicates that the suspension and damping systems are working effectively in dissipating dynamic energy and returning the vehicle to a stable condition. The curve with the fastest decline (green curve) indicates that the response drops from about 4.2 to ± 2.0 in about 10–12 seconds, indicating a relatively greater damping or more favorable mass distribution. In contrast, curves with slower descents (yellow and purple curves) take longer to reach stable conditions, reflecting greater dynamic energy or smaller damping.

At the end of the simulation, the entire curve shows a tendency towards a steady-state state, albeit with different levels of final response. This confirms that the combination of vehicle speed and mass distribution has a significant effect on lateral stability and vehicle comfort, especially in the condition of turning maneuvers while accelerating.

CONCLUSION

PO medium bus suspension system. The Marita route from Jakarta to Cianjur through Puncak Bogor was successfully modeled using Simulink and was able to represent the dynamic response of the vehicle quantitatively through the parameters of body acceleration, suspension

deflection, damping time, and damping ratio. The results of the analysis showed that spring stiffness (k) and damping coefficient (c) were the most influential parameters on the dynamic response of the vehicle, as the changes in both directly affected the RMS values of body acceleration, suspension maximum deflection, and system damping time. Optimization using Simulink resulted in an increase in damping ratio from around $\zeta \approx 0.03$ to $\zeta \approx 0.07$, which indicates that the suspension system is able to dampen vibrations more effectively without causing the vehicle's response to become too stiff. After optimization, the performance of the suspension system improves significantly. This can be seen from the RMS value of the body acceleration decreased from about 0.38 m/s^2 to 0.21 m/s^2 , the maximum deflection of the suspension was reduced from about $\pm 85 \text{ mm}$ to $\pm 50 \text{ mm}$, the damping time decreased from about 6.0 seconds to 2.5 seconds, and the damping ratio increased from ≈ 0.03 to ≈ 0.07 . In the simulation of vehicles when turning and accelerating with variations in speed and mass distribution, the optimized suspension system still shows a stable response, with the RMS of the body acceleration being below 0.25 m/s^2 and the suspension deflection remaining controlled, making it more suitable for the mountainous road conditions of the Jakarta-Cianjur route via Puncak Bogor.

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