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Conceptual Design and Feasibility Study of Gauge-Changing Bogie for Variable Gauge System

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ABSTRACT

Malaysia's railway network uses a variety of gauge lengths. Keretapi Tanah Melayu Berhad (KTMB) has been utilising a meter gauge, while the new ECRL line employs a standard gauge. Dealing with different gauges on a railway network can be tough for passengers and operators. Meanwhile, switching trains from Malaysia's East Coast to the West Coast involves changing tracks from the ECRL track (standard gauge) to the KTMB track (meter gauge). Due to the varying gauges, the freight train is required to transfer its cargo from ECRL to KTMB rolling stock. The locomotive industry acknowledges that the issue of varying gauges on railway networks presents challenges for passengers and operators. A Gauge Change Train (GCT), which connects two railway networks with different track gauges, provides a possible solution for this issue. Therefore, this paper aims to propose a design concept for a gauge-changing bogie for a variable gauge track system (standard gauge or metre gauge track). Two gauges can be adjusted on a variable gauge bogie system. It consists of a bogie system for adjusting the wheel length from the axle and a gauge-changing railroad track. In this paper, a new bogie design for APM trains and freight trains is developed, while a bogie that can be used on various track gauges was constructed using AutoCAD and Solidworks. The main feature of the new design bogie is that it will use a pneumatic suspension system to alter the length. The proposed bogie can be converted to a metre gauge or standard gauge, and such flexibility can improve the transportation industry's service in the future.

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1. Introduction

The construction of the Malaysian railway has greatly benefited the economies of its periphery and has played a crucial role in driving the industrial revolution. There is an increasing need to upgrade transportation services to mitigate the possibility of future challenges and secure the long-term viability of existing endeavours [1,2]. However, the development of railway gauge lines has been inconsistent since the inception of railways. Apart from the varying track sizes, some progress does not present a significant problem. Varying rail gauges appear to be the greatest challenge for loading and delivery. Transportation's primary purpose is to move people and goods from one place to another. Thus, infrastructure relocation must be quick and progressive, especially during an emergency. Nonetheless, the disparity in track gauge will impede such movement.

Therefore, Gauge-Change Technology (GCT) is recommended to address the issue of varying gauges. Whenever the GCT crosses over a section of track with a different gauge, it instantly adjusts the wheel gauge to the new gauge so the train can be on track without stopping. Due to its heavy construction, the automatic gauge-changing bogie used in Gauge-Change Technology (GCT) can significantly increase the setup cost of trains [3]. The technology is still necessary because switching passengers and cargo from one-gauge vehicle to the other is costly and inconvenient [4-9].

The gauge non-uniformity is acknowledged by all industrialised nations [10,11]. For instance, different rail gauges in Malaysia pose several operational challenges for the Malaysian railways, increasing the financial burden borne by passengers and those responsible for loading cargo. Moreover, it will lead to the damage of goods during trans-shipment, delay in receiving goods at the destination, theft or misplacement of goods during trans-shipment, and claims related to these occurrences. Finally, difficulties may arise in future gauge conversion projects since enlarging existing rails is labour-intensive.

Therefore, the paper aims to propose a design concept for a gauge-changing bogie for a variable gauge track system (standard gauge or meter gauge track). Furthermore, the automatic changing gauge bogie and multiple gauge track in Malaysia will be reviewed, while the concepts and approaches through the design of multiple bogie and track utilising various tools will be analysed. The paper proposes a new bogie design for APM trains, freight trains, and a bogie that can run on different track gauges in a digital environment using programs like AutoCAD and Solidworks. The proposed design can address the issue of converting gauge bogies for different gauge tracks. The automatic changing gauge bogie is applicable for multiple gauge tracks in any applicable goods train.

1.1 Variable Gauge Track in Malaysia

Standard and meter gauges are the only gauge types used on Malaysian railways. The gauge refers to the distance between the flanges of two wheels and is equivalent to the distance between the inner sides of the rails. Express Rail Link (ERL), Light Rail Transit (LRT), Mass Rapid Transit (MRT), and the brand-new line East Coast Rail Link (ECRL) are the major rail operators that use standard gauge [12-15]. On the other hand, Keretapi Tanah Melayu Berhad (KTMB), which consists of two main lines, KTM West Coast and KTM East Coast, is the major rail operator that uses metre gauge [16-19]. The only topics of conversation are the ECRL standard gauge and the KTMB metre gauge, both of which are utilised by the People Mover or Automated People Mover (APM) Trains and the Freight Trains.

The predecessor of KTM, the Federal Malayan Railway State (FMSR), had developed the metre gauge since the days of British colonial rule [20]. The new rail project, known as the ECRL, comprises lines currently operating with standard gauge [20,21]. A track that transfers a break of gauge from

ECRL (standard gauge) to KTMB (meter gauge), and vice versa, may be required if APM trains and freight trains coming from Malaysia's East Coast are required to be transported to the West Coast within a certain amount of time. A track transfer of a break of gauge is therefore required. As a result of the differing gauges, passengers on the train need to transfer to another rail line, and the goods train has to relocate its cargo from the ECRL to the KTMB one item at a time [17,21]. Hence, it incurs inconvenience to all related users.

1.2 Gauge-Change Technology (GCT)

A gauge-changing bogie is different from a regular bogie. This type of train, which can also be referred to as Gauge Changing Technology (GCT), is a train in which the bogie can change gauges while the train is running. This technology is a solution for running railway vehicles on two or more gauges to compensate for differences in track gauges. It is possible to adjust the gauge of the bogies by removing them from one group and placing them in a different group [4,22-23]. This innovation originates from the CRRC Changchun Railway Vehicles factory, the largest rolling stock manufacturer in the world, owned and operated by the state. This train must either stop at a gap in the gauge or wait for new bogies to be installed. On the other hand, the new high-speed trains have bogies that can adapt to a variety of rail gauges as well as supply voltages. These bogies are equipped with variable-gauge technology. The gauge-changing train may be an intriguing option for clients to travel abroad [24-26].

The GCT was developed as one of the solutions to the problem of gauges breaking. Accelerating technological progress will significantly impact the economy and the natural world. From an economic standpoint, the CGT can shorten procedures so trains do not have to frequently stop for gauge wheelset system adjustments, reducing the total expenses and encouraging market penetration. The development will promote longer-term competitiveness, higher productivity and innovation, lower overall production costs, and higher revenue. Moreover, applying GCT will positively impact the environment by lowering fuel consumption, energy consumption, and carbon emissions. Employing such a configuration that lowers this output is environmentally conscious and has financial advantages [27,28]. This technology can carry both people and bulk quantities of goods, save energy and space, have a high level of safety, a low level of pollution, an increased level of ecological friendliness, and efficiency superior to that of road transport. In addition, the variable gauge bogie system would call for a much smaller network of waggons to be used in order to accomplish the same amount of traffic work. There will only be a very slight delay for wagons currently in transit. It helps to reduce expenses associated with transportation and bogie exchange [13].

2. Methodology

A new gauge-changing bogie was developed using 3D CAD design software such as SolidWorks and AutoCAD. This new bogie design prioritises creating a bogie capable of functioning on several different track gauges. The structural evaluation for variable gauge bogie was conducted to determine how successfully the transition could be made from standard gauge railway 1435 mm to meter gauge railway 1000 mm and vice versa. The objective was to develop a concept for a bogie that could be used on a Gauge Change Train (GCT), resulting in an improved railway system. The flowchart shown in Figure 1 presents the complete workflows.

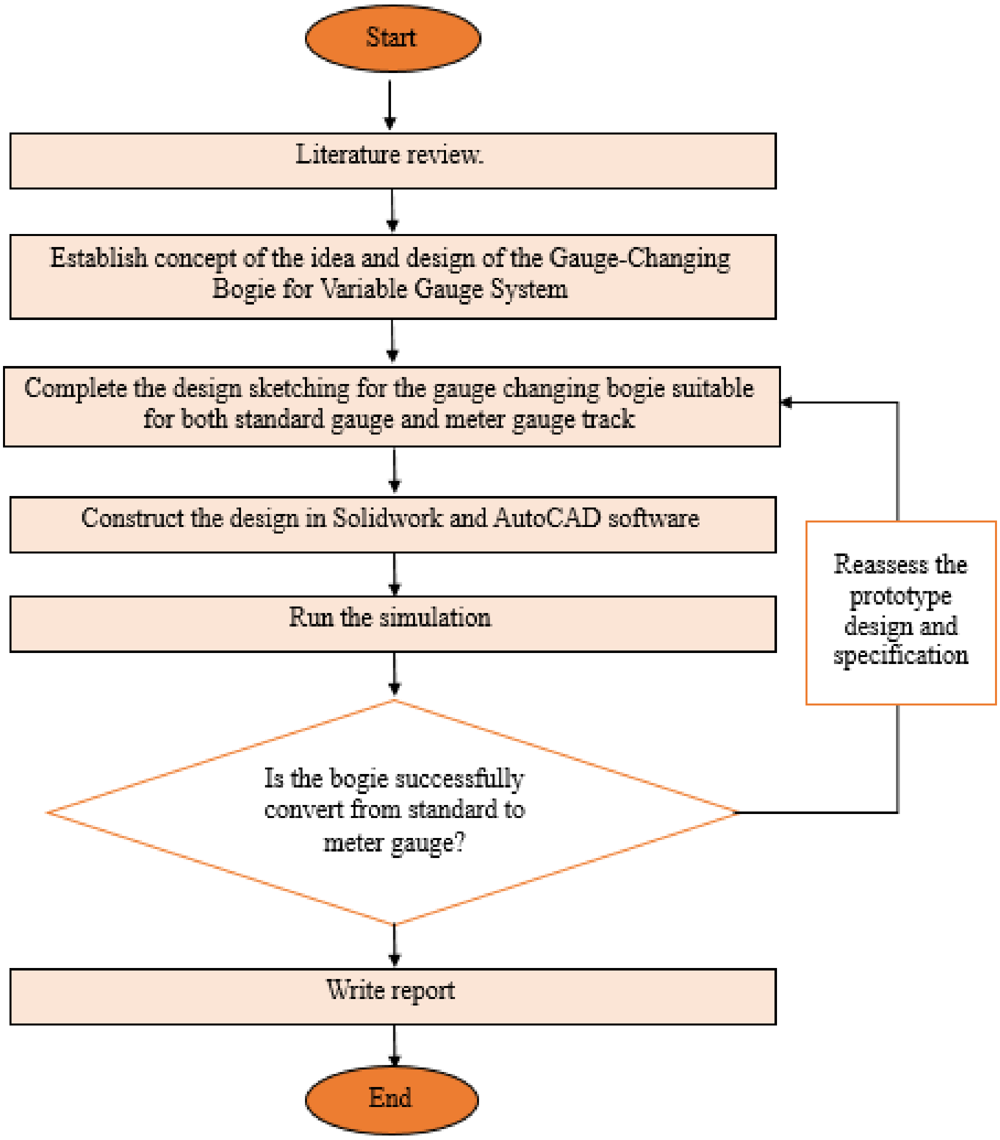

Fig. 1. Flowchart proposed in designing the GCT

2.1 Material

The first step is the design process, which aims to supply the bogie with a technical specification that fulfils all of the necessary requirements and contains all of the required information. After that, these designs were put through their paces in computer simulations so that adjustments could be made.

CAD was employed to conduct the initial design, which was later revised with new ideas and modifications. The locking capability of the lorry chassis is required for both the design phase and the finished bogie product. The involved components are the axle, wheel, axle box, and ICF bogie frame. This type of bogie can operate on the rail gauge with a width of either 1435 mm or 1000 mm. The configuration needs to allow for easy access to perform any necessary maintenance. This new bogie design can now be found in the cast steel category.

2.2 Conceptual Design Documentation

The primary framework of this design is a lorry chassis comprised of two individual parts that connect and merge to form a unified chassis. When one of the semi-chassis is moved with the other, the latch or locking device alters the width of the semi-chassis, either increased or decreased. Subsequently, two pneumatic suspension axles are attached to each end of the semi-chassis. Four axles are connected to either the vehicle's outer or inner axle. This suspension system, which includes both the inner and the outer axles, will change the length, and the latch on the semi-chassis will lock the selected length into place after the suspension. After that, two wheels will be attached to each edge of each axle, bringing the total number of wheels to four. After that, the axle box is positioned to support the vehicle's weight, transferring weight to the wheels and allowing for rolling and longitudinal motion (see Figure 2).

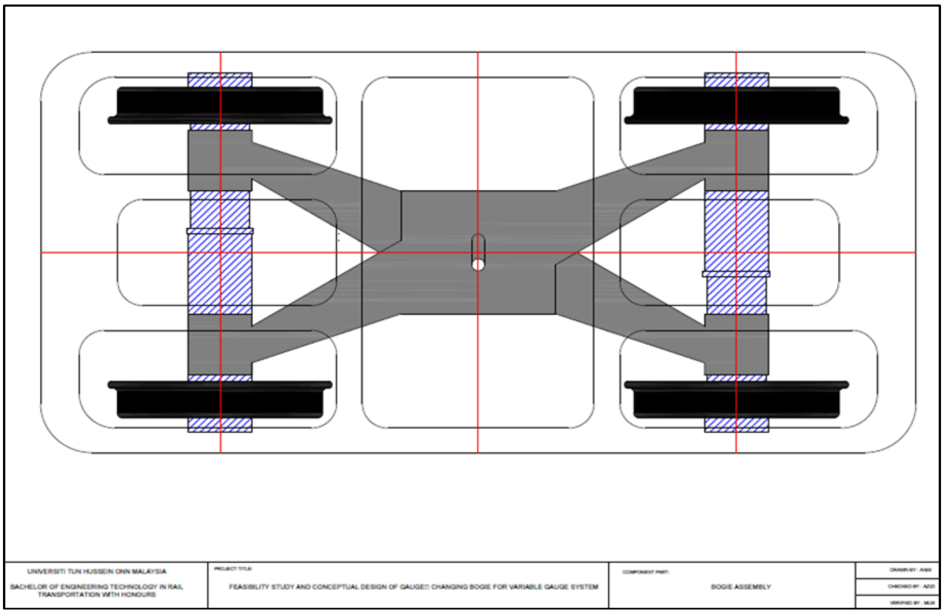

Fig. 2. General conceptual design and final bogie product

3. Result and Analysis

The primary components of the bogie are as follows: the wheel, the inner axle, the outer axle, the lorry, the axle box, and the bogie frame. This axle has a guided pneumatic suspension axle to avoid spinning. The inner axle of this guided beam is placed into the holes in the outer axle, while the holes in the outer axle have a sliding bearing against their corresponding inner surfaces. Drawing inspiration from a European patent [23], which presented a variable-gauge wheel set for a railway vehicle, a new and improved gauge-changing bogie is designed. The bogie's outer and inner bearing design was influenced by the patent's depiction of independent drive wheels directly coupled to coaxial motors. Pneumatic systems are selected to ensure safety. Moreover, the pneumatic systems only require compressed air in operation. They do not pose a significant risk of electrical shock because no electricity flows in the system except the compressor. Work is made easier by the pneumatic suspension system, which increases the force that must be applied to an object from a purely mechanical perspective. A direct consequence of the design is creating a mechanical advantage, achieved by multiplying the force with the bogie, resulting in the end outcome. The wheel can move in conjunction with the guided pneumatic suspension axle because the guided axle in the bogie can glide in a horizontal direction.

The axle box is fixed in the longitudinal direction, and the wheels are placed on either side of the axle arm. The axle itself is fixed in the transverse direction. The motor system that drives the wheel is direct drive (DDM). The DDM concept was taken from a European patent and incorporated into the research. This patent describes a bogie with two pairs of wheels powered independently. Particularly, this vehicle has its motors located where the wheels are. Consequently, it is possible to implement independent driving using a basic design in which each wheel can rotate independently. Reducing the number of unnecessary components and directly driving the application decreases the risk of individual parts failing or becoming dysfunctional. Hence, direct-drive motors are excellent choices for applications that demand high speed and acceleration despite their compact size. The wheel can spin in its own right. Both the guided axles are suitable for standard gauge positions, and one includes a meter gauge. The wheel gauge is held firmly in place by this axle, which is secured by inserting the inner axle into the hole of the outer axle.

3.1 Gauge Conversion Process Flow

In order to facilitate the process flow and simulation testing carried out with SolidWorks, the automatic gauge changeover technology includes the installation of a variable-gauge axle system. When the running rail spacing between trains of one gauge is changed to that of another gauge, this is gauge conversion. The gauge can be altered by taking the train through a gauge changer or other equipment designed for that purpose. The path either becomes significantly wider or significantly narrower. Unlocking the train's wheels allows this bogie to be adjusted, after which the wheels are either brought closer together or moved further apart before being locked back into place. During converting gauges, bogie cars must move from the metre gauge to the standard gauge. Once there, the inner and outer pneumatic suspension axles must automatically release, and the bogie car must glide outward for approximately 190 metres while keeping the wheel in place to achieve the metre gauge's required width. After the guided position of the metre gauge has been secured, it can be permitted to move along the tracks.

Moreover, the bogie wheels can pass at the rail gauge change from standard to metre gauge. The pneumatic suspension axle needs to be adjusted so that it is pushed 625 metres closer together in the new position. The adjustment is done when the train changes from standard to metre gauge. This gauge shift is made possible by a one-of-a-kind configuration close to the points where various railroads depart from the network. This invention features a locking or lock-releasing mechanism; one of its components is a sliding latch. This latch will be used to adjust the width of the bogie as needed. The locking mechanism used on the semi-chassis was also taken from a patent held in the United States. Simply sliding between the traverses on the semi-chassis makes it possible to alter the rail gauge at any time. Perhaps the United States patent served as the inspiration for the concept of a locking or unlocking mechanism. The locking mechanism system contributes to the coupling and uncoupling of the two connectors and fixing the two components in their operational position. Additionally, the system helps to connect and disconnect the two components. The vehicle's wheels are each equipped with a mechanism that employs automated gauge variation to re-establish contact with the rail and keep the wheels moving forward (see Figure 3 and 4).

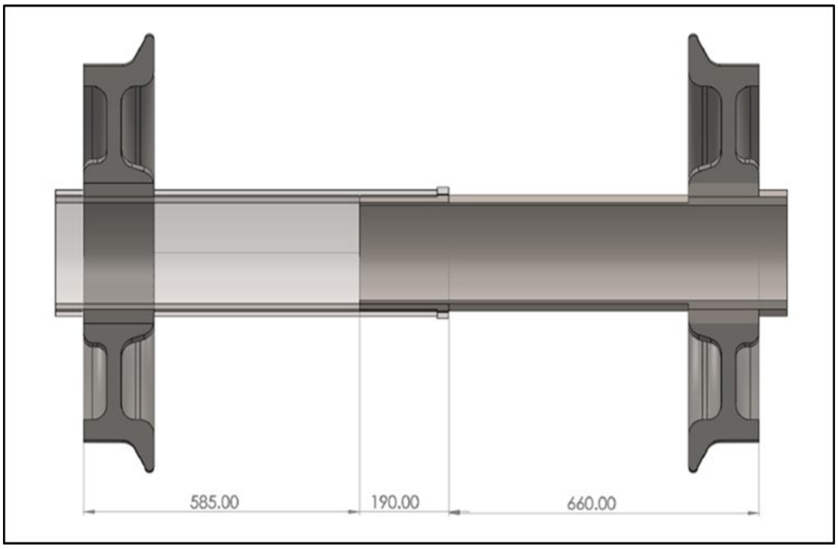

Fig. 3. Process flow of pneumatic suspension axle glide outward around 190 mm to Standard Gauge Width

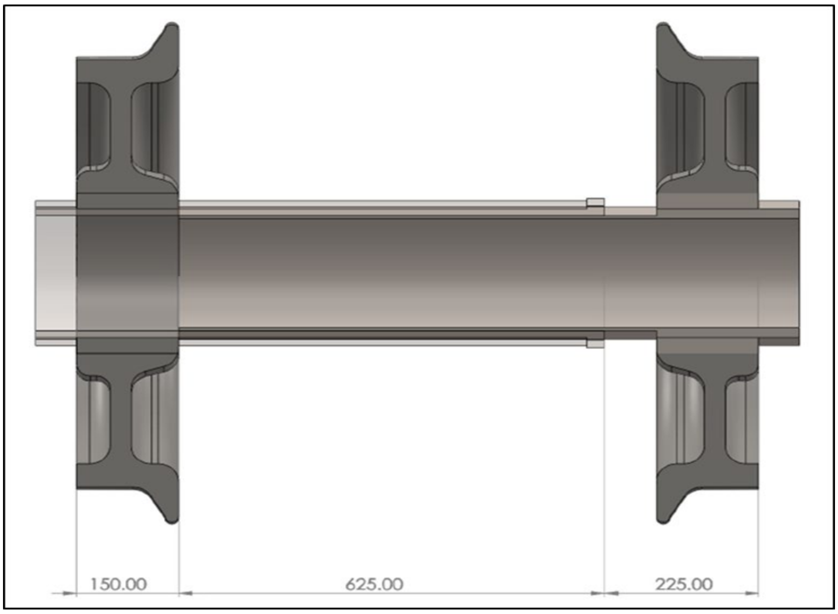

Fig. 4. Process flow of pneumatic suspension axle glide outward around 625 mm to Meter Gauge Width

3.2 Simulation Model

The SolidWorks simulation software was utilised to analyse the gauge conversion performance. The simulation was successful since the specification applied to the simulation was taken from one of the four patents referenced. The wheel was the first built-in component added. The flange, tread, hub, and hub fillet are all other components of this wheel. The wheel is then secured using the sleeve nuts on the axle. Steel with the AISI 1060 or 1070 designation is frequently used to make train wheels. The next component is the axle for the pneumatic suspension, which consists of two distinct parts: the outer axle and the inner axle. A pair of inner and outer axles are utilised, with the inner axle positioned within the outer axle. Connecting the inner and outer axles requires a pneumatic suspension, which can be converted from standard gauge to metre gauge or from metre gauge to standard gauge. A high-carbon steel that is commonly used for the construction of railway axles.

The next component, the axle box, which acts as a bearing between the axle and the frame of all railroad cars, is fastened to the wheel at the axle's sleeves. This component is attached to the wheel at the axle's sleeves. The axle box served as a shock absorber buffer between the bogie frame and the axle bearings. Casting steel or ductile casting iron are common materials for constructing axle boxes. As a longstanding structural element for rail cars, the semi-chassis comprises two distinct components that combine to create a single chassis, enabling one semi-chassis to move in relation to the other. This is because the semi-chassis is formed by two separate components that combine to create one chassis. Steel and aluminium are common components in its construction. There will be a clasp that joins the two halves together in the centre of the chassis. The chassis will appear broader when the latch slides outward to represent the standard gauge and smaller when the latch slides inward to indicate a metre gauge. The pneumatic suspension axle, installed at each end of the chassis, will move along with the width as it is altered.

When gauges are changed, bogies must be moved from the metre gauge into the standard gauge. It is necessary for the inner and outer pneumatic suspension axles to automatically release and glide outward for approximately 190 millimetres in order to achieve the standard gauge width. The guided location of the metre gauge is then fixed before being permitted to travel on rails. When a train is converted from standard to metre gauge, the pneumatic suspension axle must be modified so the bogie wheels can pass through the new location. This modification involves moving the axles 625 millimetres closer together. A special layout close to the network's departure locations for multiple railways allows this gauge adjustment. The ICF bogie frame is a structure designed to unite all of the vehicle's components and support the total weight of the vehicle. In most cases, a box section layout is used to manufacture the bogie frames, and the material of choice is steel. The bogie frame will be equipped with several slots, which will be used to accommodate the wheel, axle, and chassis as necessary (see Figure 5-8).

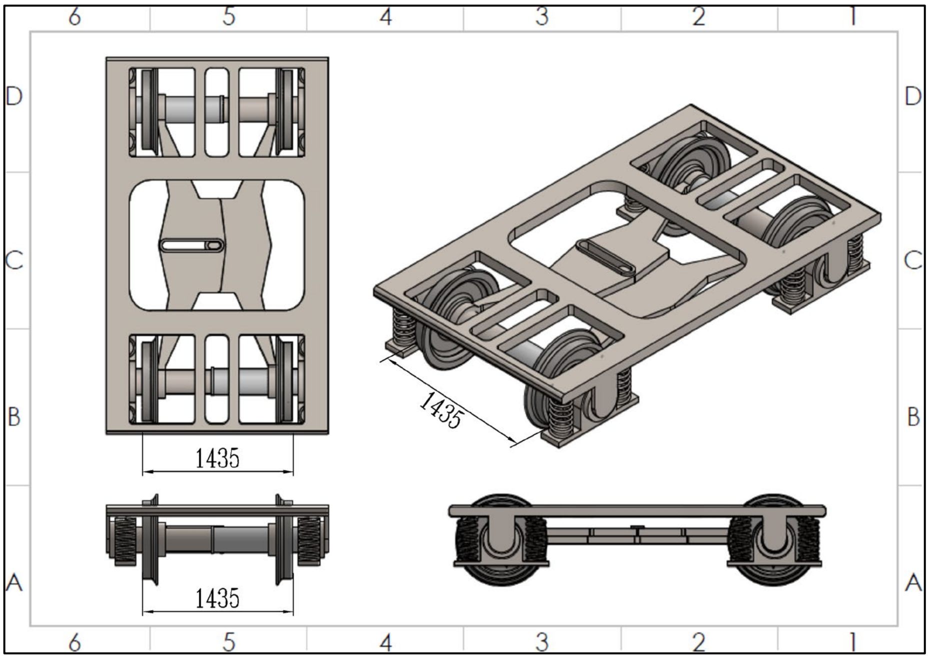

Fig. 5. Complete setup of Gauge-Changing Bogie for Standard Gauge System

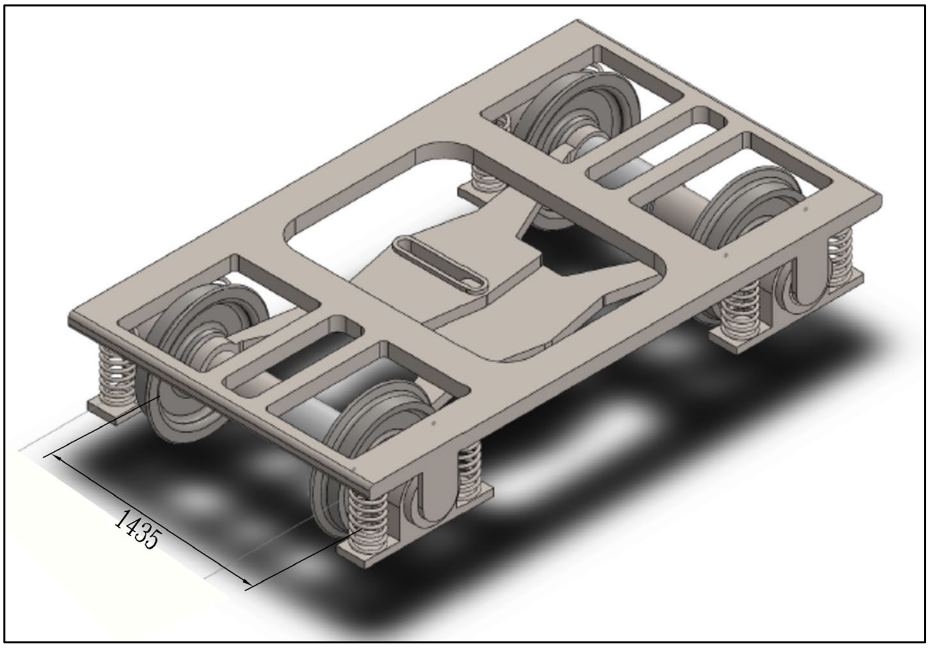

Fig. 6. Full isometric view of Gauge-Changing Bogie for Standard Gauge System

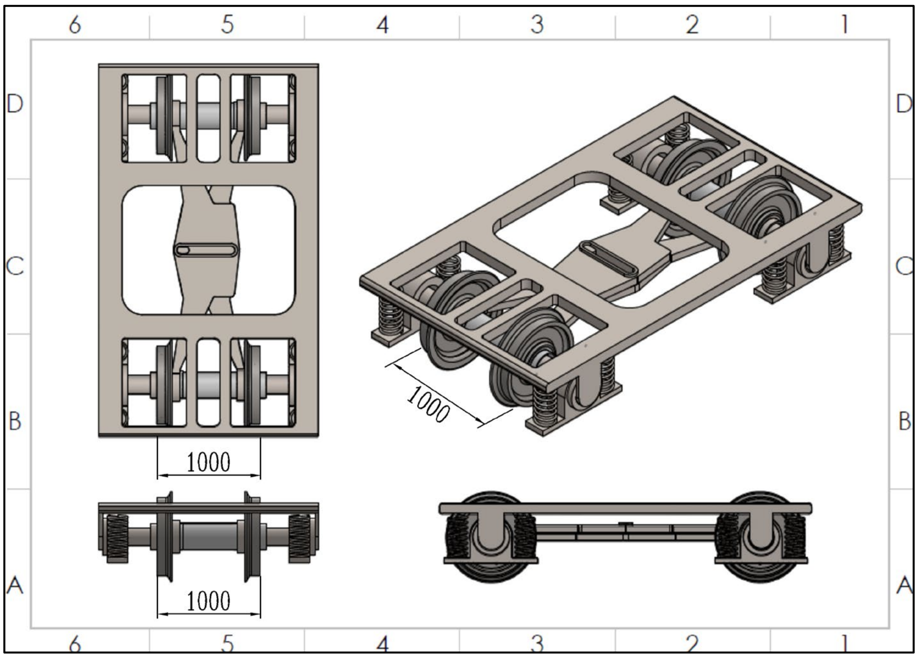

Fig. 7. Complete setup of Gauge-Changing Bogie for Meter Gauge System

The difference between the standard gauge and meter gauge systems refers to the distance between the inner edges of the rails, also known as the track gauge. Standard gauge typically refers to a track gauge of 1435 millimetres, the most commonly used gauge worldwide. Meter gauge, on the other hand, refers to a track gauge of 1000 millimetres, which is narrower than standard gauge and is used in some regions due to historical or geographical constraints.

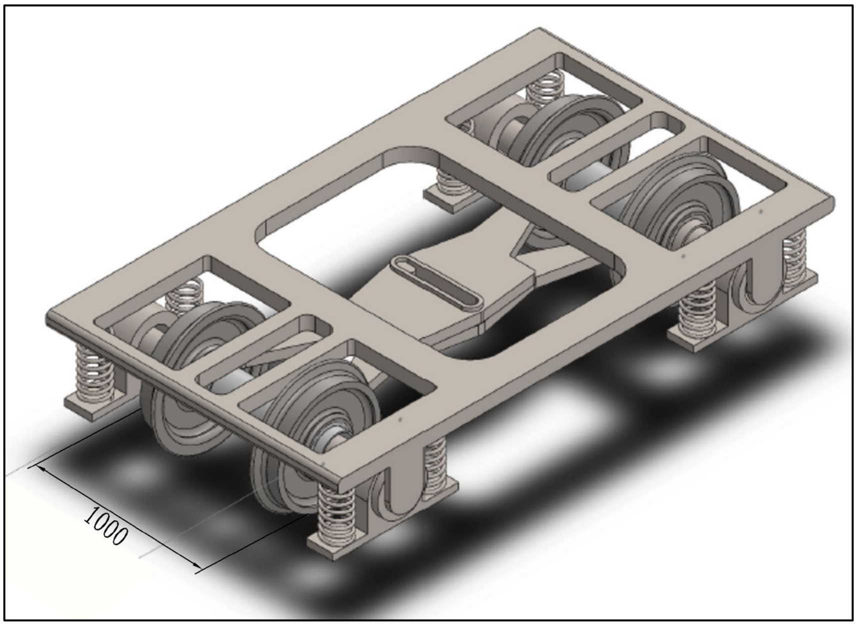

Fig. 8. Full isometric view of Gauge-Changing Bogie for Meter Gauge System

4. Conclusions

In conclusion, the paper provided a solution to connect multiple gauge tracks applicable in Malaysia and globally. Malaysia's automatic changing gauge bogie and multiple gauge track have been systematically reviewed. In addition, the ideas and strategies utilised in designing multiple bogies and tracks using various tools have been analysed, and the concept design for a gauge-changing bogie for a variable gauge track system (standard gauge or metre gauge track) has been presented. Thus, it is possible to build variable gauge changing bogies not only for metre gauge and standard gauge but also for board gauge and narrow gauge. This will increase the effectiveness of railway transportation systems and help to solve the difficulties associated with transhipment and bogie exchange, leading to an improvement in the operating ratio of the railway system. Despite this, there are still many challenges to face and overcome. The top priorities include enhancing dependability and durability and providing extra safety measures.

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