JURNAL INFOTEL
VOL. 17, NO. 4, NOVEMBER 2025, PP. 854–871. DOI:10.20895/INFOTEL.V17I4.1349

RESEARCH ARTICLE

Optimization of Limit Switch Usage as a Motion Boundary Detection System in a Dolly System

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Received: April 22, 2025; Revised: August 31, 2025; Accepted: September 12, 2025.

Abstract: Efficient container handling is a critical aspect of global trade, as container terminals serve as the primary hubs connecting maritime transport and inland logistics networks. The increasing demand for faster and safer container operations has encouraged the adoption of the double chassis (dolly) system, which significantly accelerates loading and unloading activities. However, this system is also prone to operational risks. Extreme maneuvers performed by truck operators can cause collisions between the dolly triangle and the chassis frame, potentially resulting in structural damage, reduced equipment lifespan, and a higher risk of accidents. To address this challenge, this study proposes the optimization of limit switches as a motion boundary detection system in the dolly mechanism to improve both safety and operational efficiency. The research combines experimental testing with mathematical model-based simulations, employing trigonometric analysis to determine the safe maneuvering angles of the dolly system. The proposed system integrates limit switches on the towing hitch to detect critical angles and provide early warning through two alarm levels. The first alarm is activated at angles less than 40° as an initial safety signal, while the second alarm is activated at angles less than 50° to prevent severe collisions. The results demonstrate that the proposed system effectively minimizes collision risks with a relatively low error rate, particularly at smaller maneuvering angles. The main contribution of this study lies in presenting a practical and low-cost safety mechanism that integrates simple sensor technology with mathematical modeling, offering an innovative solution to support safer and more efficient container terminal logistics.

Keywords: chassis, dolly system, limit switch, stopper, towing hitch

© Jurnal Infotel ISSN: 2085-3688; e-ISSN: 2460-0997

1 Introduction

Container terminals play a crucial role in the global logistics chain by ensuring the efficient and safe movement of containers. According to UNCTAD, more than 80% of global trade by volume is carried by sea, making container terminals a critical hub to sustain international supply chains [1]. Operational efficiency and safety are therefore key factors in maintaining the smooth flow of container movement within container terminals. An innovation to accelerate container loading and unloading is the double chassis (dolly) system, which allows trucks to transport two containers in a single operation, thereby significantly reducing turnaround time. At PT. Terminal Petikemas Surabaya, the use of head trucks with the dolly system has been implemented as one of the strategies to improve port performance and competitiveness [2,3]. However, in addition to its benefits, the dolly system also poses significant operational safety risks. Extreme maneuvers can cause collisions between the dolly triangle and the chassis frame, leading to structural damage and increased accident risks. To address these risks, the double chassis head truck has been equipped with a Safety Device Dolly System (SDDS) that functions as an early warning system. Previous studies have shown that integrated safety systems are effective in minimizing risks. For example, Zhang et al. demonstrated that automatic motion sensor monitoring systems reduced accident rates in logistics operations by up to 35% [4]. Similarly, Lee et al. found that the application of automated safety feedback in container handling equipment increased operator response speed and reduced downtime by 22% [5].

A key component of SDDS that must be optimized is the motion boundary detection system. This research focuses on utilizing a limit switch sensor to automatically detect critical angles and provide early warnings to the operator, preventing collisions and enhancing operational efficiency. Studies in industrial equipment have shown that limit switch–based detection systems improve accuracy and safety by providing real-time boundary feedback without requiring extensive infrastructure changes [6–8]. At PT. Terminal Petikemas Surabaya, this system has been integrated into the towing hook dolly, enabling automatic feedback that assists drivers to control the maneuver limits more precisely [9].

Despite these advantages, several challenges remain. Previous research has highlighted that the calibration and integration of limit switches into existing dolly systems is not always straightforward, as they must adapt to the standard towing hitch used in container terminals [10, 11]. In addition, variations in operational conditions, such as maneuvering angles and field distances, can affect the detection performance. Therefore, an optimization strategy is required to determine the most efficient sensor configuration that balances safety, efficiency, and compatibility with the current infrastructure.

The purpose of this research is to develop an optimized limit switch–based motion boundary detection system for the dolly system by combining experimental methods with mathematical model–based simulations. This study evaluates maneuvering angles, resulting field distances, detection error rates, and provides an optimal design that can be adapted across different dolly systems. Ultimately, the findings are expected to contribute to safer, more efficient, and more adaptive container terminal operations, offering both theoretical value and practical applications for the logistics industry [12].

2 Research Method

2.1 Research subjects

2.1.1 Limit Switch and Stopper

Limit Switch-a device that works to turn off and turn on electrical currents in a circuit due to its structural mechanical features. Mechanically operated with three terminals: the central terminal, the NC terminal, and the NO terminal [13]. Mild to moderate physical interaction with other objects can connect or disconnect an electrical circuit to detect the motion limits of a system using a limit switch sensor. This sensor works by actuation, when the sensor's lever or plunger compresses against a stopper. The sensor generates an electrical signal that indicates that the spot has been reached as soon as the stopper presses the limit switch actuator [14]. This mechanism is widely implemented in industrial automation systems, especially in the regulation of heavy equipment position control and movement in the transportation and manufacturing sectors [15]. The main advantage of a limit switch compared to other sensors is that they can operate even under extreme environmental conditions (e.g., very high temperatures or high-vibration environments) without the need for an additional power source for actuation [16]. In the dolly system, limit switches are used in container terminals to stop or change direction of vehicles after reaching designated boundaries set by the stopper [17].

In this system, when the dolly reaches a certain point, the stopper presses the sensor actuator, activating or deactivating the limit switch as a mechanical component. The stopper consists of two holes, a top hole of about 10–15 mm and a bottom hole of 5–8 mm, which is designed to correct the position when actuating the sensor [14]. The pressure that the stopper exerts on the sensor actuator is the basic reason that decides whether the limit switch is on or off. As the stopper passes through the detection zone, the limit switch lever is actuated to change the sensor's condition from normally open (NO) to normally closed (NC), or from NC to NO, depending on the sensor type [15]. These systems allow the dolly system in container terminals to work accurately, improving operational safety and reducing the risk of collisions or mistakes in container transport [17].

Figure 1: Limit switch.

Figure 2: Stopper.

2.1.2 Chassis and Towing Hitch

The chassis is an integral structural element of a heavy vehicle system and is a load-bearing frame of forces for the weight of the vehicle and its components. A double chassis system consists of two separate main frames that connect to each other to improve stability and distribute load in a trailer or dolly system [18]. This double chassis structure should be able to absorb dynamic loads as the vehicle moves and must resist shocks from uneven roads [19]. A double chassis system can protect containers with such large capacity in container terminals which is designed to make the vehicle frame structure more durable [20]. The tow hitch is a link between the front chassis and the trailer or towed dolly, and is one of the essential components of a double chassis.

As part of the container transportation system, the towing hitch mounted onto the front of the chassis supports the installation of sensors that detect the motions of the dolly system. The towing hitch is the main pivot point for pulling a trailer and therefore an appropriate location for limit switch sensors to detect when a trailer is coupled [18]. The angle of the hitch can also be detected when in motion through sensors mounted on the towing hitch, where signals are relayed to the vehicle control system [19]. Temporary encampments allow the system to adjust dolly motion boundary detection, improving the operating performance of container terminal vehicles. Hence, the relationship between double chassis, towing hitch, and sensors contains very crucial characteristics in designing a more automated and precise logistics system [20].

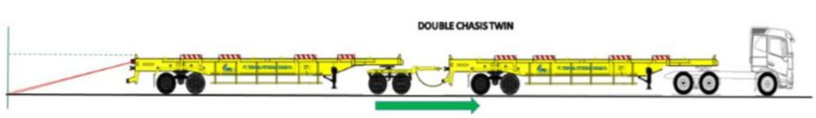


Figure 3: Double chassis twin.

Figure 4: Towing hitch.

2.1.3 Dolly system and dolly triangle

The dolly system used in freight transportation acts as an intermediary unit between the main truck used for logistics transportation and the trailer that needs to be moved. The system comprises a wheeled device that enables an extended cargo capacity as an additional trailer that is also pulled by the main device used for initial wear and tear [21]. Among the benefits of the dolly system is its load dispersion, less stress on the main axles of the vehicle, and stability during transit [22]. In addition, the dolly system can enable vehicles to operate in tighter spaces (such as container terminals) where container handling requires high maneuvrability [23].

The dolly triangle (or A-frame), one of the key elements of a dolly system, is the main connecting element between the dolly and the following trailer [24]. Tow Hitch: At the front of the dolly, this triangular-shaped structure serves as the link between the dolly and the main trailer. This triangle dolly structure is used to transfer pulling and pushing forces from the main vehicle to the dolly in addition to decoupling the transportation process [21]. This design enables a better load distribution and adds to the maneuverability of the vehicle when making sharp turns or changing directions frequently, especially on rough terrains [22]. Knowing the dolly system system and the dolly triangle system can optimize the implementation of this system to achieve better efficiency and safety related to container transport in container terminals [23].

Figure 5: Dolly system.

2.2 Tools and Materials

The tools and materials required are shown in Table 1.

Table 1: Tools and materials

No	Tools and Materials	Spesification	Volume
1	Limit Switch	TZ-8108 4	pcs
2	Proximity Sensor	Distance 25cm	1 pcs
3	Sensor Bracket	80 × 160 × 6 m/m S 45C	1 pcs
4	Sensor Box	85 × 160 × 3 m/m S 45C	2 pcs
5	Stopper	160 × 260 × 6 m/m S 45C	1 pcs
6	JFL	M10 × 20 m/m	3 pcs
7	L-Bolt	M6 × 20 m/m	4 pcs
8	Cable	3 Core 2.5 mm	25 meter
9	3-Pin Waterproof Socket Plug	3 Pin	3 pcs
10	Skun	2.5 mm	10 pcs
11	Alarm / Buzzer	24 volt	1 pcs
12	Sensor Support Plate	5 × 10 cm, 6mm	1 pcs
13	Alarm Reset Push Button		1 pcs
14	Alarm Reset Relay		1 pcs

2.3 Design

This study employs an experimental design with a quasi-experimental approach. The research model involves testing the chassis before and after sensor installation to determine its effect on reducing the risk of fractures

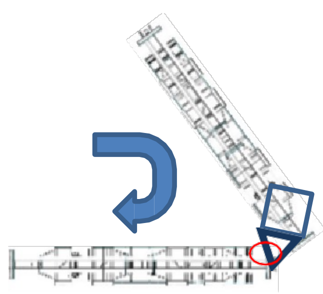


Figure 6: Dolly system during a turning maneuver.

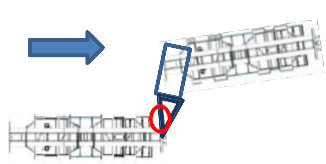


Figure 7: Dolly system during a reversing maneuver.

From Figure 6 and Figure 8, when a truck passes through the container block area at the container terminal, the operator often performs extreme turning or reversing maneuvers to align the truck with the loading and unloading area. These maneuvers are executed at an angle of less than 45 degrees between the dolly triangle and the frame of the chassis. Such sudden maneuvers typically occur due to limited visibility or time pressure during loading and unloading operations. As a result, accidents occur where the towing dolly triangle collides with the front section of the chassis frame. This strong impact causes deformation in the dolly triangle, resulting in bending, while the chassis frame sustains dents and structural damage. This damage not only compromises the vehicle's structural integrity, but also disrupts operational efficiency and poses safety risks in the work area.

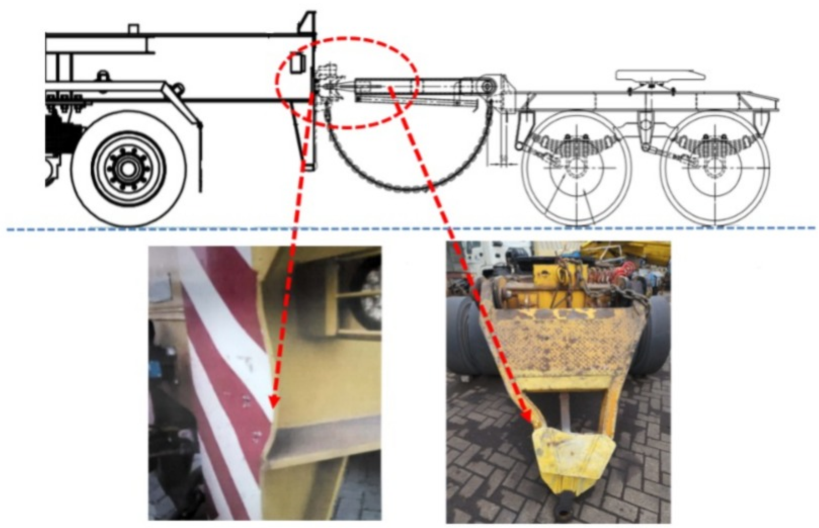


Figure 8: Chassis frame damage.

Based on the collision between the towing dolly triangle and the chassis frame due to extreme maneuvers, a new solution has been developed: the use of limit switch sensors installed on the towing hitch as a motion boundary detection system. It is intended to alert the operator and prevent them from exceeding the safe maneuver angle. When less than 50-degree angle of maneuvering (angle between the dolly triangle and chassis frame) is reached, Limit Switch 1 is activated which triggers Alarm/ Buster 1. If the angle of the maneuver becomes sharper, under 40 degrees, then Limit Switch 2 identify the condition and activates the Alarm 2, which has a higher sound than Alarm 1, so it easy to notify the Maneuver Operator to stop or adjust the maneuver immediately. This detection system aims to prevent collisions and reduce the risk of damage to the dolly triangle and the chassis frame. The design for the installation of the limit switch sensor is shown in Figure 9. The details of the installation of the limit switch sensor are shown in Figure 10.

The image above shows details of the installation of the limit switch sensor on the tow hitch. The lower section contains Limit Switch 1, which detects movement and provides an initial warning. Meanwhile, the upper section contains the Limit Switch 2, which detects extreme movements at angles below 40 degrees.

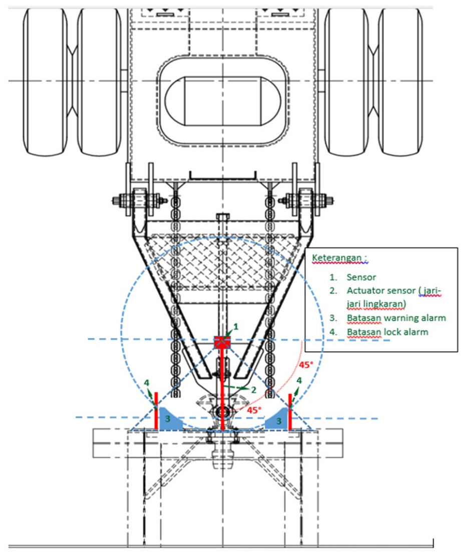
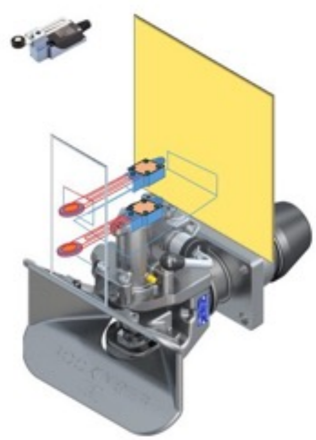


Figure 9: Limit switch sensor installation design.



(a)

(b)

Figure 10: Limit switch sensor design.

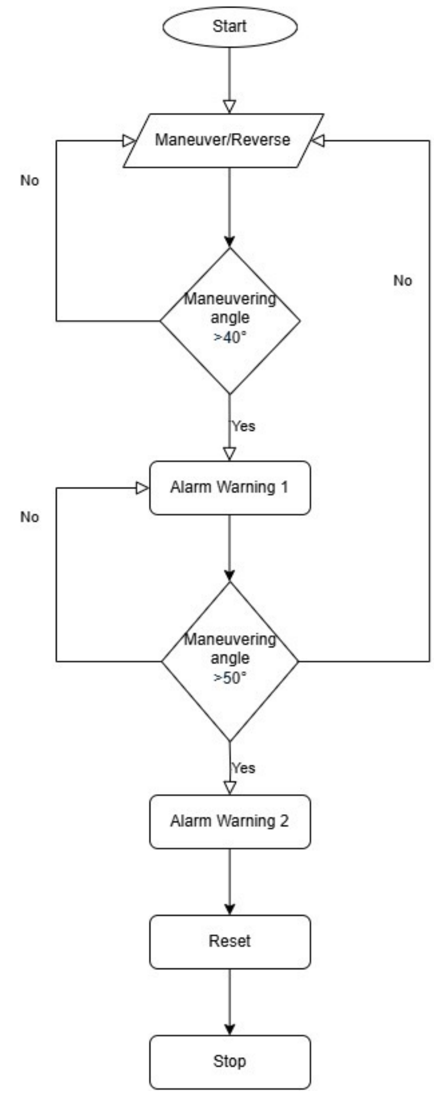


Figure 11: Flowchart reverse maneuver process.

The flowchart above illustrates the reverse maneuver process, which is controlled by two limit switches based on the retreat angle. The process begins with the "Maneuver/Reverse" command, after which the system checks whether the maneuver angle > 40°. If so, then Limit Switch 1 will be activated, and Buzzer 1 will turn ON. If not, the system will continue to maneuver under safe conditions. Next, the system re-examines whether the retreat angle > 50°. If this condition is met, then Limit Switch 2 will be activated and Buzzer 2 will turn ON. However, if not, there are two possibilities. The first possibility is that Buzzer 1 will turn ON because the system is maneuvering within the range of 40° < Maneuver Angle < 50°. The second possibility is that the system will continue to maneuver under safe conditions. Once both limit switches have operated according to the specified conditions, the process proceeds to the next mechanism, namely the reset phase, where this process will be inspected by a mechanic before the system finally stops. If, at any stage, the angle does not meet the required conditions, the process will return to the beginning until the angle requirements are fulfilled.

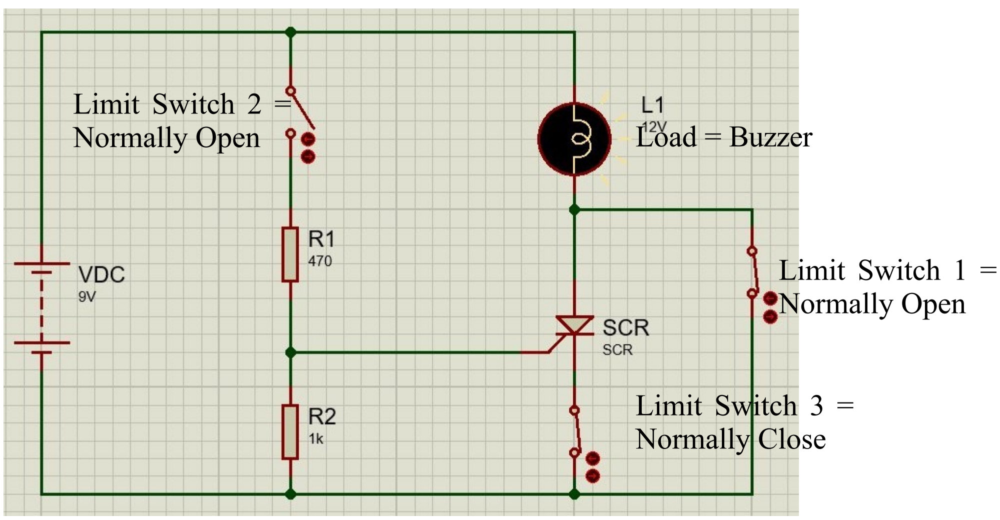


Figure 12: Dioda SCR.

The image above depicts a Silicon Controlled Rectifier (SCR) circuit, which functions as an electronic switch to control current within a system. This circuit consists of a VDC power source, two resistors (R1 and R2), a trigger switch, and a load in the form of a lamp. The operation of this circuit begins when the trigger switch is pressed, supplying current to the SCR gate, thereby turning the SCR ON and allowing current to flow from the anode to the cathode, which lights up the lamp. Once the SCR is activated, it remains ON even after the switch is released, unless there is an interruption or a manual disconnection of the current. The second switch in the circuit serves as a reset switch, cutting off the current flow to the SCR, turning off the lamp, and restoring the system to its initial state.

The relationship between the SCR concept and the previous flowchart is that the limit switches in the flowchart act as triggers, similar to the switch in the SCR circuit. When the system reaches a certain maneuver angle, Limit Switch 1 is activated (maneuver > 40°), functioning like the trigger switch in the SCR. If the maneuver continues until the angle exceeds 50°, Limit Switch 2 is activated, which then initiates the next mechanism, such as activating an alarm or an indicator lamp within the system. In other words, in a larger system such as a dolly system, SCRs can be used to control components such as alarms or automatic shutdown mechanisms based on the position of the limit switches, aligning with the motion limit control flowchart of the dolly system.

2.4 Sample Collection Technique

The sampling technique in this study utilizes a triangle on the dolly system to determine the distance between the frame chassis and the angle formed by the dolly system during maneuvering. Sampling is conducted under two conditions: standard samples and field samples, to compare the distances obtained at specific maneuver angles.

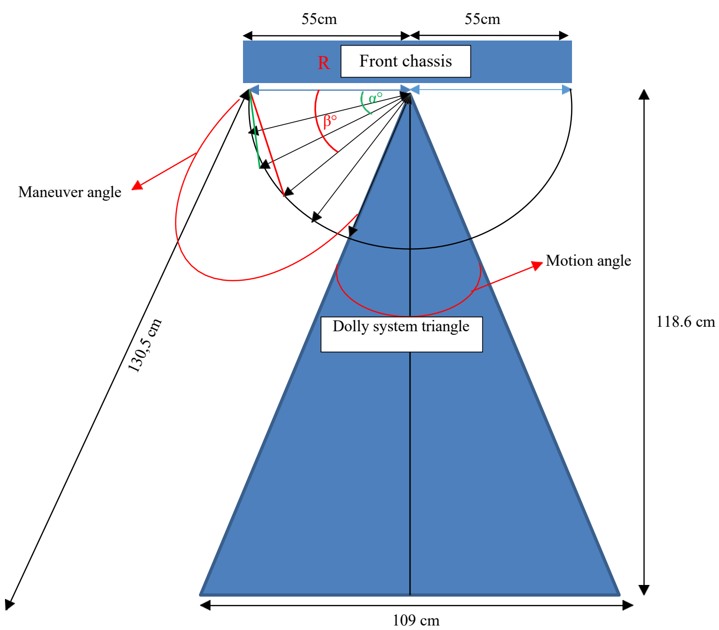
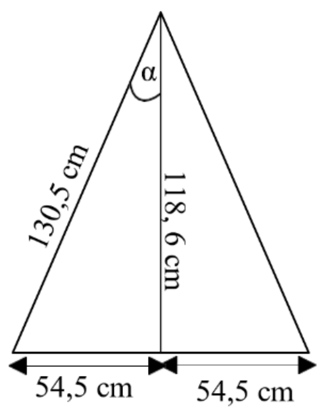


Figure 13: Triangular structure in the dolly system.

The dimensions of the dolly system triangle used in both standard samples and field samples have equal side lengths. This triangle has a vertical side length of 118.6 cm, a hypotenuse of 130.5 cm, and a horizontal side length of 190.5 cm. Additionally, the front chassis frame has a length of 110 cm. By determining the angle formed during maneuvering, the distance between the chassis frame and the dolly triangle can be calculated using trigonometric principles, specifically the law of cosines. This calculation aims to understand the relationship between changes in the dolly angle and the minimum safe distance that must be maintained to prevent collisions. The smaller the maneuver angle, the shorter the distance between the dolly and the chassis frame, increasing the risk of a collision. Therefore, this sampling process is crucial in designing a motion limit detection system using limit switch sensors mounted on the towing hitch. The first limit switch will activate at an angle of less than 50 degrees to provide an early warning to the operator, while the second limit switch will activate at an angle of less than 40 degrees as a critical warning, prompting the operator to immediately adjust the maneuver direction to prevent workplace accidents and damage to both the dolly and the chassis frame.

2.5 Statistical Analysis and Modeling

The analysis in this study employs a trigonometric approach to calculate the relationship between the angle formed by the dolly system and the distance between the dolly triangle and the chassis frame. The statistical model used includes comparative analysis to compare distances at standard angles and field-measured angles, as well as regression analysis to determine the influence of the angle on the safe distance. The angle calculation is performed using the sine trigonometric formula with the following scenario:



$$\text{Sin}(\theta) = \frac{54.5}{130.5}$$

$$\text{Sin}(\theta) = 0.41$$

$$\theta = \arcsin 0.41$$

$$\theta = 24°$$

Figure 14: Angle calculation using trigonometric equations.

A 24° angle was obtained as a reference in the field. Meanwhile, the standardized reference angle that has been determined is 48.7°, as shown in the following image.

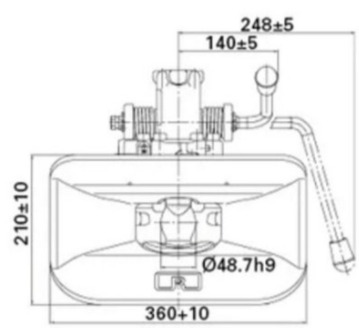


Figure 15: Standard angle 48.7°.

Figure 16: Field angle measurement diagram.

To calculate the distance between the chassis frame and the angle generated by the dolly system, a complementary angle approach is calculated by Eq. (1)

$$\text{Distance} = \text{Chassis frame length} \times (\sin 90^\circ - \theta) \quad (1)$$

In this case, the frame length of the front chassis is 55 cm. This formula is used because the term $(\sin 90^\circ - \theta)$ represents the difference in orientation between the dolly and the frame. This analysis enables the identification of a safe distance at various maneuver angles, which serves as the basis for determining the activation threshold of the limit switch sensor to prevent collisions. Using this model, the operator can understand how changes in angle directly affect the safe distance during truck maneuvers. The determination of sensor usage can be established by calculating the error values and the percentage of error values by comparing sensor readings with testing instruments. If the error value is known, the sensor can be deemed suitable and suitable for the chassis. Eq. (2) is used to determine the error value.

$$\text{Error} = \frac{|x - x_1|}{|x|} \quad (2)$$

Meanwhile, Eq. (3) is used to determine the percentage of errors.

$$\%\text{Error} = \frac{|x - x_1|}{|x|} \times 100\% \quad (3)$$

3 Result

This section presents the research findings obtained from testing the motion limit detection system using limit switch sensors on the dolly system at the Surabaya Container Terminal. Angle measurements were conducted using the trigonometric formula Eq.(1), as described in the analysis and statistical model section. In addition, error calculations were performed between the theoretical distance and the actual distance to evaluate the accuracy of the designed system, using Eqs.(2) and (3) . The data collected are presented in tabular form to facilitate analysis and comparisons between the standard conditions and the actual field conditions. Measurements were conducted by increasing the maneuver angle of the dolly system in $10°$ steps, starting from the previously determined model and the statistical value of $24°$ up to $90°$. The measurement of the field angle begins at $24°$, as the dolly triangle naturally forms a $24°$ angle. Meanwhile, the standard angle measurement starts at $48.7°$, based on the established standard. However, to balance the error value results with the field angles, the measurement starts at $28.7°$ and extends up to $90°$. It is important to note that the angles presented in the table represent motion angles, whereas the trigonometric calculations are based on maneuver angles. The calculations can be referenced in trigonometric Eq.(1).

Table 2: Table presents the research results obtained

No	**Standard Angle**(°)	**Field Angle**(°)	**Standard Distance** (cm)	**Field Distance**(cm)	**Error**(%)
1	28,7	24	48,24	50,24	0,04
2	38,7	34	42,92	45,59	0,06
3	48,7	44	36,30	39,56	0,08
4	58,7	54	28,57	32,32	0,13
5	68,7	64	19,97	24	0,20
6	78,7	74	10,77	15,1	0,41
7	88,7	84	1,24	5,7	3,59
8	90	90	0	0	0

From the table, it can be observed that as the angle increases, the distance between the dolly and the frame decreases. At a standard angle $28.7°$ with a field angle $24°$, the standard distance is 48.24 cm, while the field distance is 50.24 cm, with an error of 0.04%, indicating a high level of agreement between theory and practice. The error begins to increase at larger angles; for example, at a standard angle of $88.7°$ and a field angle of $84°$, the error reaches 3.59%, as extreme maneuvers are difficult to control with precision.

In this study, two alarms were installed to detect potential collisions:

Alarm 1: Serves as an early warning to alert the operator to exercise caution. Based on the table, the safe distance becomes critical when the motion angle reaches $48.7°$ (standard), resulting in a maneuver angle of $41.3°$ between the frame and the dolly system triangle, with a field distance of 39.56 cm. Therefore, Alarm 1 is activated at a motion angle of $40°$ to provide an early warning when the distance approaches the safe limit.

Alarm 2: Serves as a critical warning, indicating that the angle has reached a hazardous level. At a motion angle of $58.7°$ (standard), the maneuver angle between the frame and the dolly system triangle is $31.3°$, with a field distance of 32.32 cm, which poses a high risk of collision. Therefore, Alarm 2 is activated at a motion angle of $50°$ to prevent collisions as the distance further decreases.

4 Discussion

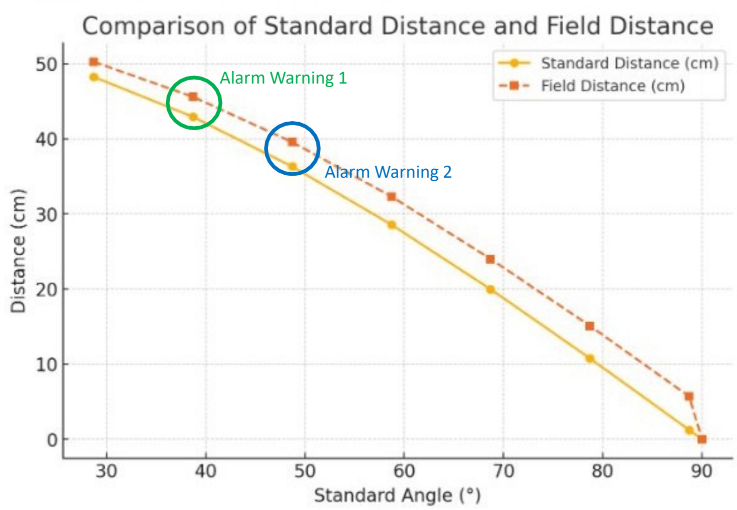


Figure 17: Graph diagram of standard distance and field distance comparison.

Based on the research findings, the comparative analysis between the standard distance and the field distance indicates that the method used is reasonably accurate in relation to the results obtained, despite some minor discrepancies. These differences are reflected in the relatively low error values at smaller angles, which tend to increase at larger angles, particularly as they approach $90°$. This discrepancy can be attributed to environmental factors, measurement errors, or changes in the position of the dolly system in the field. The graph above illustrates a downward trend in distance as the angle increases, which aligns with the principles of trigonometry, where the horizontal distance decreases as the angle approaches perpendicularity. According to the data, the optimal angle for Alarm 1 (early warning) is approximately $40°$, as the distance at this point remains sufficiently safe. Meanwhile, Alarm 2 (critical warning) is set at $50°$, where the distance begins to enter a hazardous range. The selection of these angles is based on the angle of motion, which achieves a balance between the alarm system's response and the operational safety of the truck in the field.

5 Conclusion

This study has successfully developed and tested a motion limit detection system at the Surabaya Container Terminal using limit switch sensors installed on the towing hitch. The primary objective of this research is to reduce the risk of fractures caused by extreme truck maneuvers, particularly when making U-turns or reversing at hazardous angles between the dolly triangle and the chassis frame. Through the application of trigonometric calculations and angle sampling in both field and standard conditions, this study has produced data that demonstrate the differences in distance between the chassis frame and the dolly system at various angles. As a result, Limit Switch 1 is programmed to detect an angle of approximately $40°$ as an early warning (Alarm 1), while Limit Switch 2 detects an angle of around $50°$ as a critical warning (Alarm 2). The error values considered are low enough to conclude that the method used is quite accurate with only the average of visible deviation for larger angles which can be caused by environmental influence and wonky field conditions. The system helps to alert operators and also helps to reduce concerns around damage to the dolly triangle and the chassis frame, helping to improve workplace safety and terminal operations.

In future studies, it is suggested to use sensor technology such as proximity sensors and gyroscope sensors that can detect angles and distances in real time with more accurate results. In addition, a system based on the Internet of Things (IoT) can be applied for remote monitoring and storage of historical data for subsequent preventive analysis. As well as these automated features, a further innovation is the implementation of a camera based visual system with image processing intended to deliver visual cueing to operators while undertaking maneuvers, significantly reducing the probable risks for human error. The first aim of this study has been achieved as an effective motion limit detection system has been designed and validated for applicability through the use of trigonometry that is firmly based on how safe maneuvering angles must be determined under operational conditions. Abstract: Container handling of the container terminal is a process with high-frequency operation and high-tech content, which has significant risks in the entire production process. The authors believe that future studies using more advanced technological methods could help improve terminal loading and unloading safety, speed, and accuracy even further.

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