A MONITORING DEVICE OF FORKLIFT'S STABILITY TRIANGLE

Mohamed Ali Emam[1], Mostafa Marzouk, Sayed Shaaban

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ABSTRACT: In most branches of industry forklifts are used for lifting and handling various shaped loads. These machines classified as lifting trucks vary in size and might be equipped with various attachments to enable work as universal lifting cranes. However, the main issue related to their usage is their critical stability that causes a lot of accidents resulting in human and material losses. These machines have been gone through years under development so as to render them more and more stable; the present research is a trial and a step forward towards better passive stability of forklifts. This research aims at enhancing the forklift longitudinal stability by monitoring the status of the so called forklift "stability triangle", and at keeping the forklift operators working within stable range of load and speed. A new monitoring device which locates the forklifts center of gravity (C.G.) during its forward movement (uphill and downhill) instantaneously displays the C.G. point together with the stability triangle. In addition, a warning red light will be lightened in case the C.G. point tends to get out of the stability triangle or, in other words, in case of dangerous situations that might lead to forklift tipping-over.

KEY WORDS: forklifts stability, stability triangle, monitor, safety

UREĐAJ ZA PRAĆENJE STABILNOSTI TROUGLA VILJUŠKARA

REZIME: U većini grana industrije viljuškari se koriste za podizanje i rukovanje teretima različitih oblika. Ove mašine se klasifikuju kao vozila za dizanje tereta različitih veličina i mogu biti opremljena uređajima kako bi mogli da se koriste kao univerzalni kranovi. Međutim, glavni problem sa njihovim korišćenjem je njihova kritična stabilnost koja izaziva mnogo nesreća dovodeći do ljudskih i materijalnih gubitaka. Ove mašine su prošle godine razvoja, kako bi se učinile što stabilnije. Prikazano istraživanje je pokušaj da se poboljša pasivna stabilnost viljuškara. Ovo istraživanje ima za cilj poboljšanje podužne stabilnosti viljuškara i praćenjem položaja takozvanog trougla stabilnosti viljuškara, a u cilju zadržavanja položaja operatora viljuškara u stabilnom opsegu opterećenja i brzine. Novi uređaj za praćenje locira centar masa (CG) viljuškara tokom njegovog kretanja napred (uzbrdo i nizbrdo) i trenutno prikazuje tačku CG zajedno sa trouglom stabilnosti. Pored toga kao upozorenje crvena lampica svetleće u slučaju da tačka CG teži da izađe iz trougla stabilnosti, ili drugim rečima u slučaju opasnih situacija koje bi mogle dovesti do prevrtanja viljuškara.

KLJUČNE REČI: stabilnost viljuškara, trougao stabilnosti, kontrolni uređaj, bezbednost

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A MONITORING DEVICE OF FORKLIFT'S STABILITY TRIANGLE

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1. INTRODUCTION

Forklifts are actually classified into eleven (11) categories, from hand pallet trucks to counterbalanced trucks and including more than 50 different types. Each one of them can be ordered with different capacity and loading range to meet different needs. The loading capacity is from 0.75 t - 8.5 t. The maximum lifting height can be up to 14.8 m [1]. As a result of various uses of hundreds of thousands of forklifts worldwide and due to forklift instability, a large number of accidents occur that lead to the loss of loads, damage of forklifts and injury to operators each year. The need for solving this problem of forklift stability occurs mainly in a number of different circumstances, such as: when the forklift is moving on uneven surfaces, while turning on a tight radius, accelerating and braking, at the beginning and the end of lifting or lowering, maneuvering the forklift, when lifting a tall stack loaded on the forks, when unloading, when the angle of the chassis of the forklift to the load is a maximum, when the forklift is angled on an adverse camber and when the forklift is braking suddenly from high speed [2]."OHSA estimates forklifts cause about 85 fatal accidents per year, 34,000 accidents result in serious injury and 61,800 are classified as non-serious" [3-4]. One of the most important causes of such accidents refer to the forklift design which due to nature of work should have a narrow track and a variable CG [4].

2. STABILITY TRIANGLE

A stability triangle is determined by three points (A, B, C) as shown in Figure 1 (a). The point "A" is the midpoint of the rear axle and the two other points "B" and "C" is the two front tires mid points located at the front axle. This brings us to the imaginary stability triangle. In order to maintain a stable forklift, its center of gravity must be kept within the stability triangle area. The most stable area while handling a load is close to the base of the forklift. If the load you are carrying moves too far forward from the forklift's base, it will more than likely tip forward, Figure 1 (b) [5].

Forklift dimensions such as: wheel base, overall width at front axle, weight distribution between axles and height of load lifting are factors that affect its stability. The forklift stability should be investigated in both longitudinal and lateral directions as the operating conditions such as: the speed of cornering, the speeding up and braking rates, and the lifting rates and heights affect the forklift stability in these directions.

Investigation of forklift stability can be done on a tilt table test rig that allows the determination of the critical level of forklift instability, as Figure 2 shows. From the figure, it

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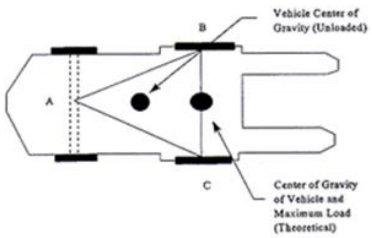
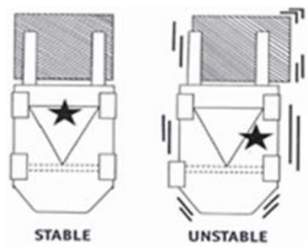
can be concluded that the forklift will be stable in case the vertical line passes through the point of combined C.G. of the forklift and the load falls within the triangle of stability [6].



(a) [5]



(b) [6]

Figure 1 Triangle of stability of the forklift

The longitudinal stability of the forklift is achieved by its rear counterbalance weight but in many situations (dynamic and static) the stabilizing moment it creates is less than the destabilizing moment created by the load lifted and in such cases it will tip over [6]. The forklift's stability system consists of 3 points of contact with ground for a three wheeled forklift or 4 points for a four wheeled forklift as seen from Figure 3. When loading the forklift to its maximum capacity, the combined C.G. shifts to the front axle and the stability will be endangered if it falls outside the stability triangle. Most of the counterbalanced forklifts are three-point suspended. This is true even if it has four wheels. This three-point support makes the so-called stability triangle, Figure 4 [6].

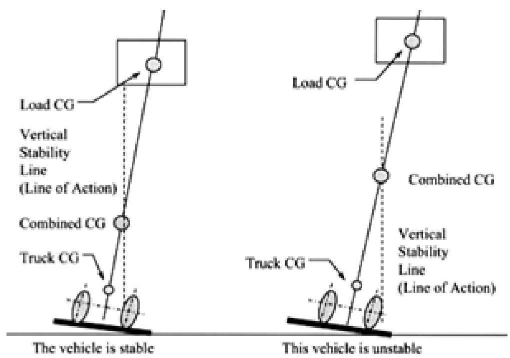


Figure 2 The vehicle in the different situations (stable and unstable) [6]

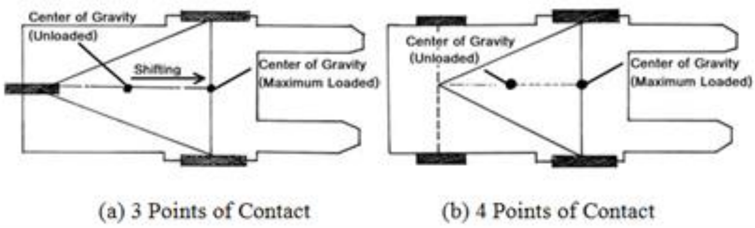


Figure 3 Center of gravity horizontal shifting illustrations [1]

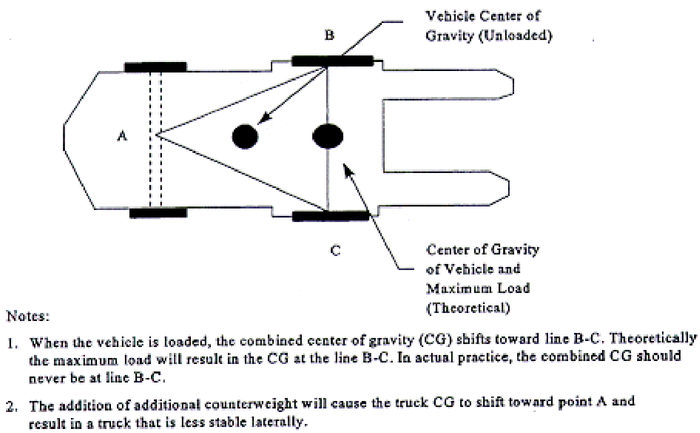


Figure 4 Three-point support forms the stability triangle [6]

To enhance the forklift stability, Toyota Co. introduced an active safety system named SAS - System of Active Stability in 1999, which aimed at protection of operators and goods as well as the truck itself [7].

The SAS is an active safety system that reduces the risk of accidents. The SAS is a computer-controlled system having 10 sensors, 3 actuators and one controller. The system sensors monitor the forklift operations and sends electric signals to the controller which outputs electric signals to the actuators so as to take corrective actions for ensuring forklift stability, as Figure 5 shows [8-10].

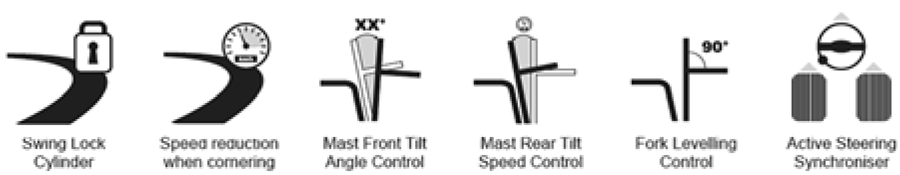


Figure 5 SAS features [8-10]

3. EXPERIMENTAL WORK (STABILITY TRIANGLE MONITOR)

A new proposal of a monitor which determines the load weight, the road inclination angle and the position of forklift centre of gravity in the stability triangle is shown in Figure 6. Figure 7 shows a layout of the stability monitoring device.

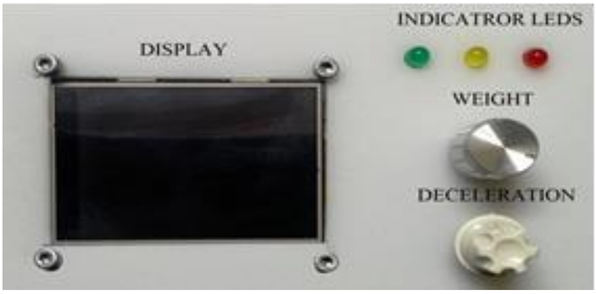


Figure 6 Stability monitoring device

The stability monitoring device consists of the following main parts:

- Arduino Mega 2560
- Gyroscope
- Light emitting diodes
- Two Potentiometers
- Weight button
- Deceleration button
- Display
- Computer.

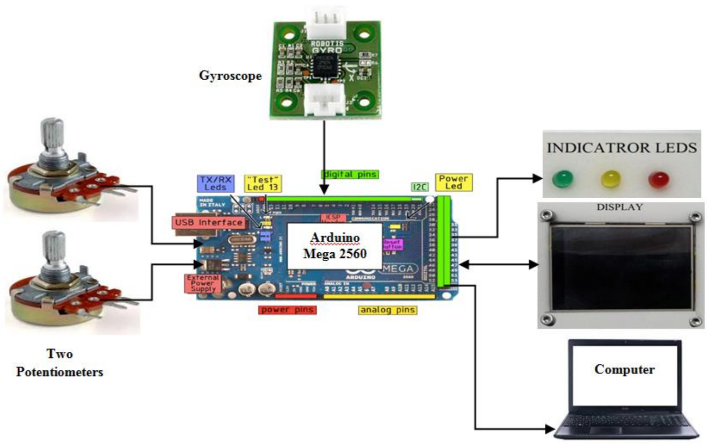


Figure 6 Stability monitoring device layout

Table 1 describes some technical specifications of the forklift.

Table 1 Forklift data

Truck mass, kg	4840
Load capacity, kg	3500
Overall width, m	1.29
Truck wheelbase, m	1.7
C.G. position from front axle, m	1.12

The Arduino processes the input data determined by the weight button, deceleration button and gyroscope to locate the forklift center of gravity position (C.G.) relative to the stability triangle on the display screen and indicates it by using a diode illumination. The output data are also saved in the processor memory. Figure 8 shows this process flow chart.

The Arduino Mega 2560 (Figure 9) is a microcontroller board that uses a ATmega2560 and has 14 pins used for Pulse Width Modulation output, 16 pins for analog inputs, 4 hardware serial ports, a 16 MHz oscillator, a USB connection, a power jack, an ICSP header and a reset button. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila [11-13].

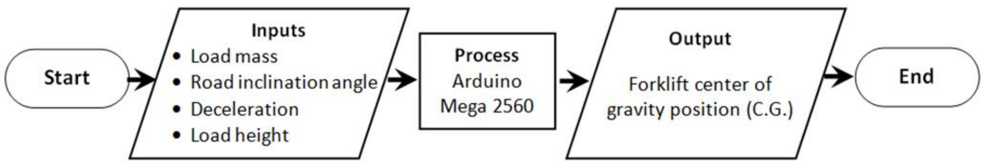


Figure 8 Flowchart for forklift C.G. determination

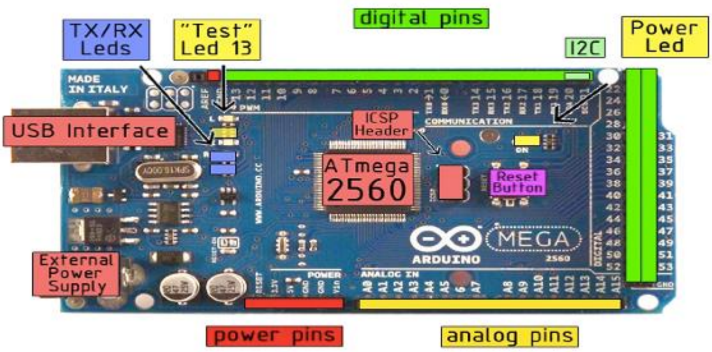


Figure 9 Arduino Mega 2560 board [13]

The gyroscope is used for sensing an inclination of the road. The sensor is installed inside the device. When the device rotates around the x-axle, the angle will be changed which refers to road inclination angle [14].

The potentiometer is variable electric resistance that controls the rate at which an LED blinks. It is connected with Arduino board and by turning the potentiometer knob it changes the electric resistance on wiper's either sides and accordingly changes giving a different analog input. When knob is turned all its way in one direction, zero volts go to the pin, and reads zero. As shaft is turned all its way in the reverse direction, 5 volts go to the pin and reads 1023. For in between turns of the pin, a number between 0 and 1023, proportional to the amount of voltage is being applied to the pin [15].

The Light Emitting Diode Indicators (LEDs) are the indicators of a stability triangle zone. When the green LED is on, that means that the situation is still in the stability triangle zone. When the yellow LED is on that means that the situation starts to be close to the danger zone of the triangle and the driver must attend. When the red LED is on that means that the situation starts to be outside the stability triangle zone and becomes dangerous, so the driver must stop the forklift operation.

The weight button is a simulator of a load sensor, which is connected with a potentiometer. Turning the button to right or left will increase the input weight or decrease it according to the product weight and the input weight it will change automatically and appear on the display. The range of the weights in this case is from 0 to 6000 kg. The range can be adjusted by Arduino 1.0 programs.

The deceleration button is a simulator of a deceleration sensor that is conneced with a potentiometer. Turning the button to right or left will increase the input deceleration or decrease it according to a specified range of brake force and the input deceleration will change automatically and appear on the display. The range of it is from 0 to 8 m/s2. The range can be adjusted by Arduino 1.0 programs.

The screen shows the stability triangle and the position of the forklift center of gravity. The position changes according to the parameters (input weight, road inclination angle, input deceleration and load center). This display is a touch screen and when putting the finger on it a keypad will appear. The keypad is used to enter the load center (see Figure 10).

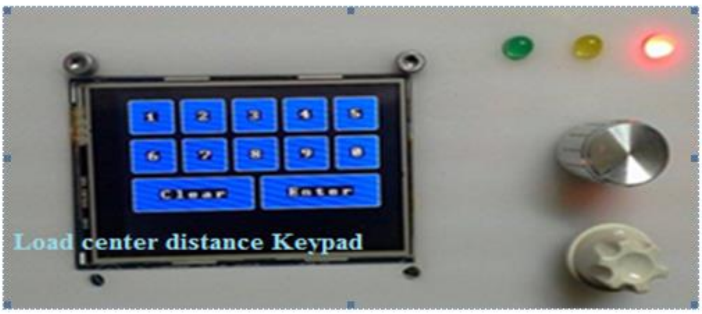


Figure 10 Keypad

4. RESULTS AND DISCUSSIONS

4.1 Effect of load mass on forklift center of gravity position (C.G.)

As shown in Figure 11, the center of gravity moves forward to the front axle with increasing the load mass. Analyzed data on effect of load mass on forklift center of gravity position are recorded in Table 2.

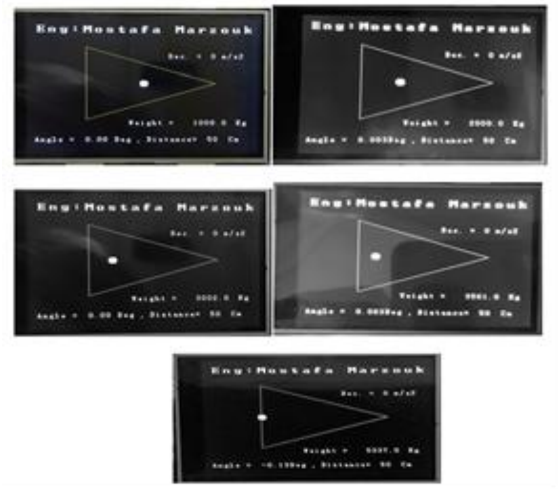


Figure 11 Forklift C.G. position at different load mass

Table 2 Analyzed data on effect of load mass on forklift center of gravity position

Load Mass (kg)	Rear reaction (N)	C.G. position from front axle (m)
1000	25916	0.754
2000	19945	0.495
3000	13975	0.300
3500	11200	0.228
5340	Zero	Zero

Where: Load centre = 0.5 m, Angle = 0^{o}, and Deceleration = 0 m/s^2.

4.2 Effect of load center on forklift center of gravity position

Figure 12 shows the position of forklift centre of gravity according to the load centre such that the C.G is directly proportional with the product load centre. Analysis of data for effect of load centre on forklift centre of gravity position recorded in Table 3. The load centre can be changed by touching the display, the keypad will appear, and then the distance is entered in cm.

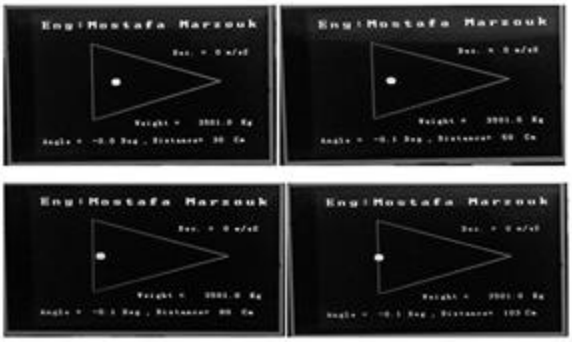


Figure 12 Forklift C.G. position at different load center

Table 3 Analysis of data for effect of load center on forklift center of gravity position

Load centre (m)	Rear reaction (N)	C.G. position from front axle (m)
0.3	15107	0.3
0.5	11200	0.228
0.8	4813	0.09
1.034	Zero	Zero

Where: Load Mass = 3500 kg, Angle = 0^o, and Deceleration = 0 m/s^2.

4.3 Effect of deceleration on forklift center of gravity position

Figure 13 shows the effect of deceleration on the position of forklift center of gravity with constant product load mass. Analysis of data for effect of deceleration on forklift center of gravity position is presented in Table 4. By turning the deceleration button right or left, the deceleration increases or decreases and the variation will be automatically displayed.

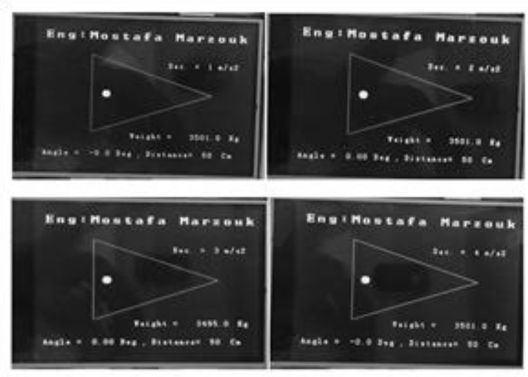


Figure 13 Forklift C.G. position at different deceleration

Table 4 Analysis of data for effect of deceleration on forklift center of gravity position

Deceleration (m/s^2)	Rear reaction (N)	C.G. position from front axle (m)
0.5	9865	0.213
1	8742	0.208
1.5	7617	0.203
2	6494	0.198

Where: Load Mass = 3500 kg, Angle = 0^o, and Load centre = 0.5m.

4.4 Effect of road inclination angle on forklift center of gravity position

Figure 14 shows the variation in the forklift center of gravity position depending on road inclination. Analysis of data for effect of road inclination angle on forklift center of gravity position is presented in Table 5. By turning the device, the angle will be changed, and it will automatically appear on the display.

Figure 14 Forklift C.G. position at different road inclination angles

Table 5 Analysis of data for effect of road inclination angle on forklift center of gravity

Angle of inclination (°)	Front reaction (N)	C.G. position from front axle (m)
5	15730	0.22
7	15383	0.228
9	15018	0.231
11	14634	0.236

Where: Load Mass = 3500 kg, Deceleration= 0m/s^2, and Load centre = 0.5m.

4.5 Effect of different load mass at inclined road on the forklift center of gravity position

The effect of the load mass at the inclined road is shown in the Figure 15. Analysis of data for effect of different load mass at inclined road on the forklift center of gravity position is presented in Table 6.

Figure 15 Forklift C.G. position at different load mass on inclination road

Table 6 Analysis of data for effect of different load mass at inclined road on the forklift center of gravity position

Load Mass (kg)	Rear reaction (N)	C.G. position from front axle (m)
1000	28871	0.77
2000	24467	0.52
3500	17862	0.26

Where: Angle = 0^o, Deceleration= $0 m/s^2$, and Load centre = 0.5m.

4.6 Effect of deceleration at inclined road on forklift center of gravity position

Effect of deceleration at the inclined road on position of center of gravity is shown in Figure 16. Analysis of data for effect of deceleration at inclined road on forklift center of gravity position is presented in Table 7.

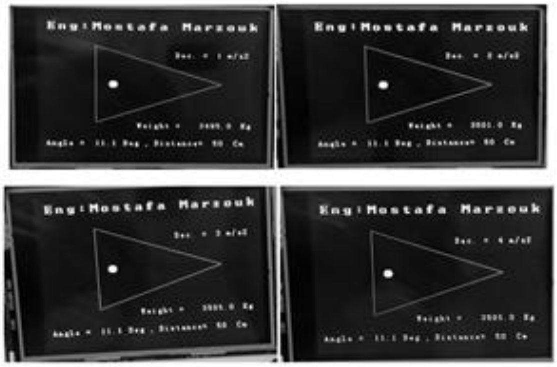


Figure 16 Forklift C.G. position at different decelerations in inclination road

Table 7 Analysis of data for effect of deceleration at inclined road on forklift center of gravity position

Deceleration (m/s^2)	Rear reaction (N)	C.G. position from front axle (m)
0.5	13813	0.28
1	12709	0.26
1.5	11605	0.24
2	10501	0.21

Where: Angle = 11^o, Load Mass= 3500kg, and Load centre = 0m.

5. CONCLUSIONS

The present research investigates how to support and enhance the field of forklift stability throughout the study of forklift longitudinal stability movement and determination of what is known as the Triangle of Equilibrium (Stability triangle). A stability safety device that is capable of monitoring the forklift stability has been designed, fabricated and tested. This monitor enables locating the center position of gravity of forklifts when carrying different loads and longitudinally moving uphill and downhill.

The safety device flashes a warning light to enable the forklift operator to get out of situations with probable instability dangers. This research can be extended to include total or partial integration of this software with hardware so analysis of loads on forklift axles are carried out and automated limits on acceleration and speed can be energized. This would ensure the safety of the operator without much dexterity on his part, which comes with experience.

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