Chapter 7
Experimental Design to Analyze a Novel Stabilization Design of a Three-Wheel Vehicle

Luis Elias Dávila-Leyva
Autonomous University of Ciudad Juárez, Mexico

Ludovico Soto Nogueira
Autonomous University of Ciudad Juárez, Mexico

ABSTRACT

Given current trends in pedal vehicles, this chapter is intended to develop a product that is capable of driving without the use of hands, for people with disabilities or for simple recreation. An apparatus was developed to measure and record the necessary parameters to design the most adequate mechanism to achieve this objective. Twelve different positions were analyzed for the user, two vertical seat positions, two inverted angle configurations of the inverted pendulum, two free degree limits of the pendulum, two wheel rotation degrees regarding the body of the mechanism, and regarding the axis motion, two axial configurations. The conclusion resulted that the function of the mechanisms was optimal.

INTRODUCTION

Due to the increment of ecologic consciousness and personal care, more and more people around the world are using alternative means of transport to the internal combustion automobiles, as electric and pedal vehicles (Reiser 2nd, Peterson, & Broker, 2002). Focusing on these last ones, we found a growing and continue innovation market, which implies two main strands for this project: inclusion and diversification. Inclusion refers that all population segments to have the capacity to choose the mean of transport they prefer and suits them best. In this case, it pretends to include people with some dysfunction, injury or amputation of the upper limbs. Meaning, they cannot drive a bicycle or tricycle even if their lower motor skills are intact. Diversification is obtained by thinking in a different way of driving a vehicle; as long as you keep focus on the road, it will allow you to occupy your hands in various activities such as

DOI: 10.4018/978-1-5225-5234-5.ch007

eating a fruit or an energetic shake on your way to college or work, take care of a fragile item, and even rest arms crossed while enjoying your drive.

Bicycles have been a means of transport widely used in all areas, both recreational and utilitarian because of its versatility, easy to use, and dynamic stability (Astrom, Klein, & Lennartsson, 2005). Even when its static stability is zero, dynamic stability resembles when a rod is balanced in one hand palm, which allows us to intuitively swing against the drop point (Schwab, 2012). In addition, the more speed it takes, the more it requires force to perform rotation, breaking the linear inertia, which paradoxically results in greater stability at a higher speed (Patterson & Leone, 2010). However, despite all the positive features of conventional bicycles, they do not meet the main requirement of diversification for the present project as they are not statically stable, that is, they do not stand on their own at rest. Static stability is essential for the application of a mechanical driving system without the use of hands. Not to mention that a recumbent bicycle is more efficient than the conventional bicycle in its biomechanics, ergonomics, kinematics, and power development (Ahmed, Qureshi, & Khan, 2015).

Even since 1896, when the first patent registration of a recumbent bicycle was made, just like the conventional bicycle, the general changes presented have been minimal; even when there are patents with some modifications in driving (Mighell, 2009), stability (James, 1941), and inclination (Roqueiro, Vieira, & Faria, 2010)

The main reason for searching a statically stable vehicle is because, if a person wants to drive without hands, the person should be getting on the vehicle should be done in the same way, which is not achieved with a bicycle. Taking into account that the most suitable position to get on and accommodate in some type of device is the sitting position (Mircheski, Kandikjan, & Sidorenko, 2014), the vehicle configuration should be one in which the user remains seated with his legs in front and his arms relaxed, starting this way from static to dynamic without altering his position. In addition, we take advantage of the fact that an ideal cardiovascular state is generated for cardiac rehabilitation, a highly recommended exercise (Kato, Tsutsumi, Yamaguchi, Kurakane, & Chang, 2011).

Starting from the premises described in the previous paragraphs, vehicles of three or more wheels will be taken into account because they have the characteristic of being statically stable, although these vehicles are not as dynamically stable as the two-wheeled vehicles. To overcome this disadvantage and introduce an innovative transport option, it is proposed to design and develop a completely mechanical system that generates a tilt in the vehicle by curving it, re-positioning the center of mass in relation to the centripetal and normal force vectors, at the time you reconfigure the position of the wheels, which would expect stability to increase.

All of this in order to be able to re-position along with the body a few centimeters of the frame and direct the vehicle without the use of hands or arms. The original design requires the investigation of all involved factors in the static and dynamic stability of the mechanism, with special attention in the immediate reaction and control derived from what will be a comprehensive analysis of the ergonomics and usability of it. In addition to the material resistance analysis and the selection of mechanical elements, submitting experimental tests to the models derived from the applied calculations.

OBJECTIVE

In the present study, it is intended to obtain all necessary data, both ergonomic and operational of the mechanism through experimentation in a mechanical system designed and manufactured to modify all positions in the seat and backrest as well as the position relative to the floor, the vertical, the inclination regarding the rotation, and the optimal graduation of the pendulum regarding the capacity of inclination of the body (see Figure 1)

METHODOLOGY

Study Design

A transversal, exploratory, experimental, and prospective study was developed to analyze a novel system of stabilization.

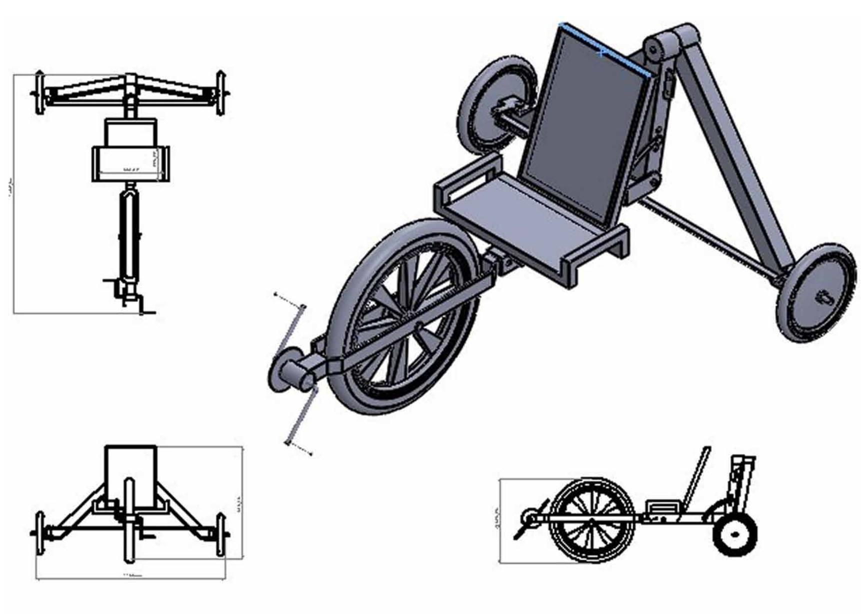
Sample

The criteria to participate in the experiment are shown in the following lines:

- Only men were accepted
- Age between 15 and 30 years
- No history of injuries and health problems
- Body weight between 70 and 100 kg

In the case of a volunteer presents injuries in back, neck, and legs their participation will be retired, and the data is not included in the analysis.

Figure 1. The different possible configurations of the device will be shown in detail



Materials

The following materials and devices were used to develop the experiment:

- The novel stabilization design cart
- Smartphone with video recorder, digital inclinometer, speedometer, and tracking distance apps.
- Orange security cones to delimitate the track.
- Metric tape
- Chronometer.

METHODS AND PROCEDURE

Taguchi Method

A qualitative and quantitative analysis about comfort perception regarding the inclination of the mechanism was made through the time spent to go over the circuit and the range movement measurements, inclination ranges, vehicle inclination, and position of the seat-backrest allowing the best performance in driving. Taguchi method (Taguchi, 1993) was applied to determine the importance of each factor to know the best performance of the device. Also, to know which is the most important factor. With the results, we will select the factors to build the final prototype.

Selection of the Factors

The selection of the factors derived from the dynamic analysis of three-wheeled vehicles to be analyzed, both static and mechanized, in the direction of inclination and adjustment of wheel configurations, taking as a key reference the inclination of the object when taking a curve, which is the repositioning of the mass center, counteracting the centripetal force generated by the friction in the steering wheels.

Taguchi methodology was applied (Taguchi, 1993) to analyze the device. This method consist is to determine all possible variables and determining which one is optimal. The factors and the test to be considered are shown in Table 1 and the tests to be performed in Table 2.

The inclination of the backrest will have two positions, which fluctuates in the optimum position for recumbent pedaling between 60 and 80 degrees. The degrees of freedom will measure how many degrees are recorded in the pendulum oscillatory movement when turning the vehicle; as well as the pendulum inclination that will start from 70 to 80 degrees regarding the vertical, changing the development of the

Table 1. Description and levels of the factors

Factor		Level 1 (degrees)	Level 2 (degrees)
A	Pendulum inclination (horizontal related)	70	80
B	Seat inclination (horizontal related)	80	60
C	Free pendulum degrees (vertical related)	30	40
D	Rear wheels turn (central axis related)	30	40

circumference described by it and by modifying the way in which the mechanism is rearranged to preserve the three support points on the ground. Finally, the relationship between the body of the mechanism, i.e. the central part, regarding the tires, parting from 0 degrees on the line to 45 degrees at the maximum curvature, or from 0 to 40, comparing the inclination achieved with the radius described in both cases and the vehicle performance.

Functionality ranges are given to each factor, then all the tests are done; each of them with all possible combinations, recording in each one the rating performance of the factors (see Table 2).

The tools to be used in the mechanism as a measuring device are: digital chronometer, a digital inclinometer, and a digital speedometer, with which you can determine with precision some of the necessary parameters for the present experimentation.

Before starting the experiment and using the function "Random. Among (lower, upper)" in an Excel spreadsheet, a random number between 1 and 8 was obtained. This number ensures that the tests order does not affect their result, that is, the volunteers will have different order when they perform the 8 different tests.

Measures

NASA-TLX

The NASA-TLX method (Hart & Staveland, 1988) was applied to assess the mental load generated by the vehicle through the different configuration planed. Participants were asked to rate six workload items – mental demands, physical demands, temporal demands, performance, effort, and frustration – each between 1 (Low) and 10 (High). An Overall Workload Index (OWI) score (ranging from 0 to 10) was calculated as the sum of the weighted ratings of the six sub-scales, divided by the number of factors as suggested by (DiDomenico, 2003). The method allows to divide the OWI into four levels depending on the final score: Level 1 = 1-25 points; no action; Level 2 = 26-50 points, medium, recommended actions; Level 3 = 51-75 points, high priority actions; and Level 4 = 76-100 points, very high, immediate actions needed (Garcia-Escutia, 2004).

Table 2. Rating performance of the factors

Test	Factor				Value			
	A	B	C	D	A	B	C	D
1	1	1	1	1	70°	80°	30°	30°
2	1	2	1	2	70°	60°	30°	40°
3	1	1	2	2	70°	80	40°	40°
4	1	2	2	1	70°	60°	40°	30°
5	2	1	1	1	80°	80°	30°	30°
6	2	2	1	2	80°	60°	30°	40°
7	2	1	2	1	80°	80°	40°	30°
8	2	2	2	2	80°	60°	40°	40°

1-10 Borg's Scale (Comfort)

Commonly, the RPE scale is used to measure the intensity of exercise. However, in this case the scale was used to rate the comfort of every test performed by the users. The RPE scale runs from 0 – 10. The numbers below relate to phrases used to rate how comfortable or not comfortable you find an activity. For example, 0 (nothing at all) would be how you feel at the end of the test if you found the test not comfortable; on the contrary, 10 (very, very comfortable) is how you feel at the end of the test if you found the test extremely comfortable.

Circuit Time Interpretation

For the unification question of comparative parameters, we proceed to make tabulation where ranges were divided from one to ten equal intervals since the other two factors that are being considered for the test analysis are based on one to ten. With which, an interaction between the three factors can be made based on the same quantification characteristic. Next, Table 4 shows the classification of the resulting time ranges, in which the longer the time of the route the less beneficial is for the performance of the test device. The lowest time (1.25 minutes) recorded circuit was taken as the minimum value and the longest time (2.12 minutes) taken as the maximum value.

Yi Calculation

The results of each test were reflected in three specific areas. The first was the general driving perception (determined by applying the NASA-TLX method). The second was the time it takes to finish the circuit. And the third was the comfort response of the mechanism to voluntary movements, the straight, and stability fidelity perceived in the curves. All of them were obtained from an interview at the end of each test. Figure 2 shows the formula to generate the objective function, that is the Yi.

Table 3. Comfort scale

Number	Interpretation
10	Very, very comfortable
9	
8	
7	Very comfortable
6	
5	
4	Somewhat comfortable
3	Moderate comfortable
2	Light
1	Very light
0	Nothing at all

Table 4. Classification of time ranges

Minimum	Minimum	Range
1.25	1.33	10
1.33	1.42	9
1.42	1.51	8
1.51	1.59	7
1.59	1.68	6
1.68	1.77	5
1.77	1.85	4
1.85	1.94	3
1.94	2.033	2
2.033	2.12	1

Values expressed in minutes

Figure 2. Objective function (Yi)

RESULTS

A total of 5 participants completed the study. The average stature was 1.76 mt, the average weight was 82 kg, and the average age was 22 years. All participants read and signed an informed consent to manifest their voluntary participation in the study.

Table 5 shows the results of the three variables measured at the end of the experiment. The test with the best results are shown in blue, that is, lower mental load, shorter circuit travel time, and greater comfort.

RESULTS EXPLANATION IN THE SUBJECTS' TABLES

The averages of both the time and the result of the sum of each arrangement were obtained, understanding that the shorter the circuit time, the best arrangement will be. As well as the addition, where the difference between comforts and the mental load sum plus the circuit time (Yi) is presented. Which, in turn, the higher the number to which it belongs the better the arrangement will be. This is shown in Table 6.

Then, Table 7 shows how the factors are divided at each level and all the tests are sum at that level. In this case, there were four at level 1 and four at level 2 in all cases. In addition, we calculate the average for each level and factors i.e. Yi is composed by the sum of the averages for every array, for example: at level Yi= *(20.8+20.2+22.6+19.8=83.4)(83.4/4=20.85).*

Lastly, a graph with the averages of each factor level is made as shown in Figure 3, which shows the difference between the levels of each factor using the Yi average for each level of every factor.

Table 5. Results for the three measures considered in the experiment

Subject 1	**Test**							
Measures	1	2	3	4	5	6	7	8
Mental load perception (NASA-TLX)	5	4	5	3	5	6	3	6
Circuit time (Track time)	8	9	9	9	8	8	9	8
Comfort-fidelity	8	8	9	8	5	6	7	5
Yi	21	21	23	20	18	20	19	19
Subject 2	**Test**							
Measures	1	2	3	4	5	6	7	8
Perception, mental load (NASA-TLX)	6	5	8	6	5	4	7	5
Circuit time	7	8	8	7	7	8	8	7
Comfort-fidelity	8	7	7	8	6	6	7	7
Yi	21	20	23	21	18	18	22	19
Subject 3	**Test**							
Measures	1	2	3	4	5	6	7	8
Perception, mental load (NASA-TLX)	7	6	8	5	4	6	9	6
Circuit time	9	9	9	8	9	9	9	9
Comfort-fidelity	8	7	7	8	7	6	6	8
Yi	24	22	24	21	20	21	24	23
Subject 4	**Test**							
Measures	1	2	3	4	5	6	7	8
Perception, mental load (NASA-TLX)	5	7	8	5	6	5	7	5
Circuit time	1	0	1	0	0	0	1	0
Comfort-fidelity	9	9	9	9	9	8	8	9
Yi	15	16	18	14	15	13	16	14
Subject 5	**Test**							
Measures	1	2	3	4	5	6	7	8
Perception, mental load (NASA-TLX)	6	5	7	7	5	4	5	5
Circuit time	9	8	9	8	8	8	9	8
Comfort-fidelity	8	9	9	8	8	7	8	8
Yi	23	22	25	23	21	19	22	21

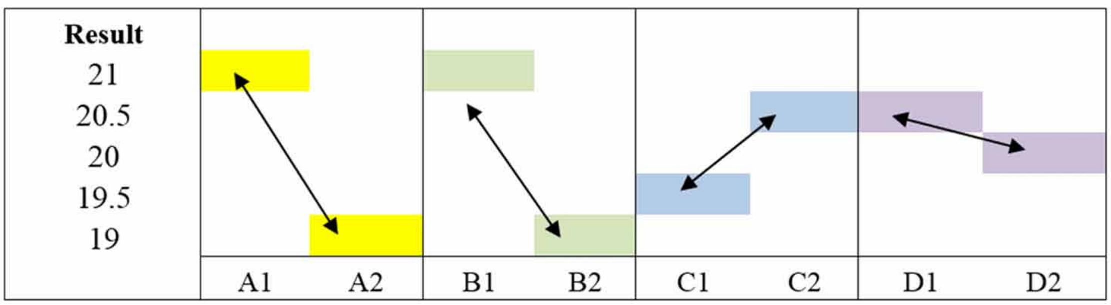
Table 6. Average scores for Yi

	Yi Test Average							
Arrangement	1	2	3	4	5	6	7	8
Yi	20.8	20.2	22.6	19.8	18.4	18.2	20.6	19.2

Table 7. Factors average at each level

Factor	Level	Addition	Average
A. Pendulum inclination	1	83.4	20.85
	2	76.4	19.1
B. Seat inclination	1	82.4	20.6
	2	77.4	19.35
C. Free pendulum	1	77.6	19.4
	2	82.2	20.55
D. Rear wheels turn	1	79.6	19.9
	2	80.2	20.05

Figure 3. Average results for every factor



The table interpretation can be explained as follows: the more vertical the line is described by the union of the two levels of each factor, the greater its importance in the product design. In this specific case, as we mentioned before, while the higher the number, the device will perform better. The factors at the corresponding level that turned out to be the highest will be considered as the arrangement that could perform a better work. The result shows that the arrangement with the best result is 3, with the factors at their respective level as follows (see Table 8).

Considering the above, the more vertical the line is the greater the importance of said factor, we can notice that factor D is almost completely horizontal, which is why it is considered that the level at which it is used is not relevant.

Table 8. Best factors

Factor	Level	Result
A	1	80 degrees
B	1	80 degrees
C	2	30 degrees
D	1	40 degrees

That said, the arrangement that comes closest to the optimal result is arrangement number 3; which contains the following parameters in Table 8. Ones that will be used as a basis for the design and manufacture of a final prototype.

CONCLUSION

For the present article, an apparatus was designed and manufactured with the ability to change the configuration in order to carry out angle modifications and required restrictions, besides expanding and contracting to adjust to the height of each individual who performs the test. With this study, we can determine the best configuration to develop a final prototype considering the specifications to get an optimal performance.

REFERENCES

Ahmed, H., Qureshi, O. M., & Khan, A. A. (2015). Reviving a ghost in the history of technology: The social construction of the recumbent bicycle. *Social Studies of Science*, *45*(1), 130–136. doi:10.1177/0306312714560640 PMID:25803920

Astrom, K. J., Klein, R. E., & Lennartsson, A. (2005). Bicycle dynamics and control: Adapted bicycles for education and research. *IEEE Control Systems*, *25*(4), 26–47. doi:10.1109/MCS.2005.1499389

DiDomenico, A. T. (2003). *An investigation on subjective assessment of workload and postural stability under conditions of joint mental and physical demands*. Virginia Polytechnic Institute and State University.

Garcia-Escutia, M. (2004). *Manual de procedimientos: protocolos de prevención de riesgos laborales*. Valencia.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, *52*(C), 139–183. doi:10.1016/S0166-4115(08)62386-9

James, D. A. (1941, November 4). *Vehicle steering and stabilizing mechanism*. Google Patents.

Kato, M., Tsutsumi, T., Yamaguchi, T., Kurakane, S., & Chang, H. (2011). Characteristics of maximum performance of pedaling exercise in recumbent and supine positions. *Journal of Sports Science & Medicine*, *10*(3), 491. PMID:24150623

Mighell, R. (2009, February 10). *Tilting wheeled vehicle*. Google Patents.

Mircheski, I., Kandikjan, T., & Sidorenko, S. (2014). Comfort analysis of vehicle driver's seat through simulation of the sitting process. *Tehnicki Vjesnik (Strojarski Fakultet)*, *21*(2), 291–298.

Patterson, W. B., & Leone, G. L. (2010). The application of handling qualities to bicycle design. In *Proceedings, bicycle and motorcycle dynamics 2010 symposium on the dynamics and control of single track vehicles* (pp. 20–22). Academic Press.

Reiser, R. F. II, Peterson, M. L., & Broker, J. P. (2002). Understanding recumbent cycling: Instrumentation design and biomechanical analysis. *Biomedical Sciences Instrumentation*, *38*, 209–214. PMID:12085603

Roqueiro, N., Vieira, R. S., & Faria, M. G. (2010). Tilting control of a three-wheeled vehicle by steering. *CBA 2010—XVIII Cong. Brasileiro de Automatica*, 3464–3471.

Schwab, A. L. (2012). Bicycling safety and the lateral stability of the bicycle. *Proceedings, International Cycling Safety Conference*.

Taguchi, G. (1993). *Taguchi on robust technology development: bringing quality engineering upstream*. American Society of Mechanical Engineers. doi:10.1115/1.800288