

Ergonomic Design of NLEX Toll Booth in the Philippines

Jenalyn Shigella G. Yandug and Marvin L. Cruz
School of Industrial Engineering and Engineering Management
Mapua University
Muralla St., Intramuros, Manila
jsgyandug@mapua.edu.ph, mlcruz@mapua.edu.ph

Abstract

Toll booth operators are exposed to number of occupational risks due to the nature of their work. According to Bureau of Labor and Employment Statistics, a total of 968 cases of occupational injuries and 1,010 cases of Musculoskeletal Disorders (MSD) were recorded for workers in toll operations (BLES, 2011). Thus, this paper aims to investigate issues surrounding toll booth operators' comfortability and safety. The main objective of this study is to provide solutions in order to minimize the prevalence of MSDs in the operations of toll road industry, particularly, to the current line of work of Filipino toll booth tellers. The researcher selected North Luzon Expressway (NLEX) as a model representation of other toll road companies here in the country since the highest volume of vehicles were passing along NLEX road. Ergonomic assessment tools and statistical analyses were used for the investigation. Based on the result of the study, it was found that the workers in the toll road industry were exposed to musculoskeletal disorders such as pain in lower back, upper back, shoulders, neck, and hips/buttocks. Similarly, based on the result of Rapid Upper Limb Assessment (RULA), the current working posture of toll booth operators could pose high level of work-related upper limb disorders due to the poor design of facility. Given this situation, an ergonomically designed toll booth was proposed. The design was based from the analysis of the study – respondent survey, anthropometric measurement, identified significant risk factors of MSD, Quality Function Deployment (QFD) matrix, and results of physical working environment assessment. It was suggested that the proposed design must be constructed in the near future for greater benefit over the present design in terms of comfortability and safety of toll booth operators.

Keywords

Ergonomic design, toll booth, toll operators, musculoskeletal disorders

1. Introduction

Toll booth is a small structure on some highways and bridges which is used to collect fees. It is operated by a toll teller that usually spend long hours of shift working inside just to collect money and/or tickets from highway motorists. Based on review of related literatures, toll booth operators/tellers are exposed to number of occupational risks due to the nature of their work. In the Philippines, operations related to toll roads and bridges are classified under Support Activities for Transportation. In 2011 statistical data of Bureau of Labor and Employment Statistics (BLES) for occupational injuries and disease, they have recorded 968 cases of occupational injuries with frequency rate, incidence rate, severity rate, and average days lost of 4.35, 10.77, 24.31, and 6.43 respectively. However, for work-related musculoskeletal diseases, they recorded 1,010 cases. 5 (0.5%) for carpal tunnel syndrome, 42 (4.16%) for shoulder tendinitis, 230 (22.77%) for neck-shoulder pain, 632 (62.57%) for back pain, and lastly, 101 (10%) for other work-related musculoskeletal diseases. In the health survey conducted by Strauss, Orris, and Buckley (1992) among 207 toll booth workers, it showed that 43.2% of their respondents had a high prevalence of central nervous system complaints (headaches, irritability, or anxiety, and unusual tiredness), mucous membrane irritation (eye irritation, nasal congestion, and dry throat), and musculoskeletal problems (joint and back pains). However, the common body parts of the toll booth workers that experienced discomfort as identified by Day, Hartman, and Casper (1996) in their study were: (1.) Neck; (2.) Upper and Lower Back; (3.) Upper Arm; (4.) Wrist; and (5.) Ankle. Both of the previous researchers concluded that further study into the musculoskeletal issues was needed to be done. From the statistical tables on nonfatal occupational injuries and illnesses requiring days away from work of U.S. Bureau of Labor and Statistics (2012), they tallied a total of 4,500 cases of Musculoskeletal disorders (MSDs) in this kind of job in private transportation industry. Also, during that year they recorded an incident rate and median days away from work of 22.6 and 10 respectively. While for occupational injuries, they recorded 8,960 cases with incident rate and median days

away from work of 15.2 and 7 respectively. Given these conditions, the authors aim to investigate issues surrounding toll booth operators' comfortability and safety. The main objective of the study is to provide solution that will minimize the prevalence of musculoskeletal disorders of toll booth operators by proposing an ergonomically designed toll booth facility.

2. Methodology

The researchers assessed the fourteen (14) toll booths along NLEX Balintawak toll plaza. The data were gathered among 50 employees. Survey questionnaires, interviews, actual measurement and review of related literatures were conducted in order to identify factors affecting the prevalence of musculoskeletal disorders among toll booth operators. Ergonomic tools such as Cornell Musculoskeletal Disorder Questionnaire (CMDQ), Nordic Musculoskeletal Questionnaire and Rapid Upper Limb Assessment (RULA) were used in the study in order to investigate the occurrence of MSDs experienced by toll booth operators due to current design of toll booth facility. Statistical analyses such as ANOVA and multiple regression analysis were also conducted in order to determine significant risk factors contributing to the prevalence of MSDs of the subjects. The identified factors were served as the basis for evaluation and development of management plan and improving the current design of the toll booth facility.

To arrive with an ergonomically designed toll booth, the standard anthropometric measurements had been used. This is the anthropometric measurements of Filipino workers from the study made by Del Prado-Lu (2007). The results of survey (NMQ, CMDQ and toll booth checklist), QFD matrix and physical working environment assessment were also been used for the design. The anthropometric measurements were able to help the researcher to solve the awkward posture of the toll teller which reduced presence of MSDs in the task. The solutions for the physical working environment were able to reduce the exposure of the workers to the workplace hazards (noise, temperature and light). The identified significant risk factors were then evaluated and subjected for the development of proposed MSD management plan and ergonomic toll booth design. AutoCAD software had been utilized for the drawing of prototype design. To control and to lessen the risk of potential failures in the design, FMEA analysis was conducted. Cost and Benefit Analysis was applied to determine the advantages and benefits of the proposed product design against the current design. For final testing, the design was evaluated through the use of 3D SSPPS software.

3. Results and Discussion

Based on survey questionnaire, interview, actual measurement and review of related literatures, the researchers were able to identify factors affecting the prevalence of musculoskeletal disorders of toll booth operators. The factors were clustered into 6 major factors such as (1) demographic (2) physical environment (3) work design (4) physical workplace setup (5) working posture (6) physiological. The summary of factors and sub-factors are shown in the table below.

Table 1. Summary of Factors Affecting the Prevalence of MSD

Dependent Variable: Y = MSD Severity			
Independent Variables			
Demographical Profile Factors			
X ₁	Age	X ₁₈	Prolonged Standing
X ₂	Gender	X ₁₉	Irregular Sleep Due to Work
X ₃	Years of Working Experience	X ₂₀	Handling of Money Bag
X ₄	Height (m)	Physical Setup of the Workplace Factor	
X ₅	BMI (kg/m ²)	X ₂₁	Physical Setup of the Workplace
X ₆	Working Hours per Day	Working Posture Factors	
X ₇	Working Hours per Week	X ₂₂	Upper Arm Position
Physical Working Environment Factors		X ₂₃	Lower Arm Position
		X ₂₄	Wrist Position
		X ₂₅	Neck Position
		X ₂₆	Trunk Position
X ₈	WBGT	X ₂₇	Back Repetition
X ₉	Light	X ₂₈	Neck/Shoulder Repetition
X ₁₀	Sound	X ₂₉	Arm/Wrist/Hand Repetition
Work Design Factors		X ₃₀	Back Exertion
X ₁₁	Shift Rotation	X ₃₁	Neck/Shoulder Exertion
X ₁₂	Number of Rest Days	X ₃₂	Arm/Wrist/Hand Exertion
X ₁₃	Irregular Break Time in Work	Physiological Factors	
X ₁₄	Working on Night Shifts	X ₃₃	Heart Rate
X ₁₅	Performance Demand at Work	X ₃₄	Blood Pressure (BP)
X ₁₆	Number of Vehicles being Served per Shift		
X ₁₇	Prolonged Sitting		

In order to identify the prevalence of MSDs among toll booth operators, the researchers used CMDQ and NMQ survey questionnaires. The results showed that lower and upper back, shoulder, neck, hips/buttocks and wrists/hands pain were the six (6) most frequent MSDs the toll tellers experienced. It also showed that the lower back had the highest risk percentage of 10.77% followed by the upper back which had 9.49%. The right shoulder, hips/buttocks, left shoulder, neck, right wrist, and left wrist were also exposed to risks with risk percentage of 7.75%, 5.97%, 8.51%, 6.44%, 4.89% and 4.91%, respectively. The results are shown in the tables below.

Table 2. Result of CMDQ

Body Parts	Frequency	% Frequency
Lower Back	41	13%
Upper Back	39	12%
Shoulders	38.5	12%
Neck	36	11%
Hips/Buttocks	33	10%
Wrist	28	9%
Upper Arm	26	8%
Forearm	19.5	6%
Thigh	18.5	6%
Lower Leg	18	6%
Knee	14.5	4%
Foot	12.5	4%

Table 3. Result of NMQ

Body Parts	Problems during the last 12 months in:	Normal activities being prevented from your problem in:	Problems in last the 7 days in:	Consulted a Doctor or avail health care utilization in the last 12 months in:
Neck	34	33	31	9
Shoulders	37	38	35	7
Elbows	21	15	16	1
Wrists/Hands	27	31	24	7
Upper Back	40	35	38	9
Lower Back	45	34	41	8
Hips/Thighs	30	22	27	4
Knees	19	21	15	4
Ankles/Feet	20	23	17	5

The researchers also evaluated the current working posture of toll booth operators using the Rapid Upper Limb Assessment (RULA). Based on the analysis, the operators are exposed to high level of work-related upper limb disorders due to the current design of toll booth facility. The RULA result shows a score of 7 for both toll transaction of the subjects handling class-1 and class 2 & 3 vehicles. This indicated that the design of the toll booth particularly the workstation used needed to be investigated and changed immediately. The result is shown in the figures below.



Figure 1. Current Working Posture of Operators

Similarly, the researchers also assessed the physical working environment of toll booth facility in order to determine other risk factors affecting the prevalence of MSDs among toll booth operators. The result of the assessment is shown in the table below.

Table 4. Assessment of Physical Working Environment

<i>Assessment Name</i>	<i>Standard Value</i>	<i>Actual Value</i>	<i>Difference</i>	<i>Remarks</i>
<i>Thermal Environment</i>				
WBGT	66 – 79 °F (19 – 26 °C)	80.48 °F (26.93 °C)	1.48 °F (0.93 °C) (Negative)	Risky
% Relative Humidity	20 - 85%	86.03%	1.03% (Negative)	Risky
<i>Acoustical Environment</i>				
Intermediate Noise Level	10.56 hours	8 hours	2.56 hours (Positive)	Safe
Noise Dose	100%	76%	24% (Positive)	Safe
TWA	90 dBA	88 dBA	2 dBA (Positive)	Safe
<i>Visual Environment</i>				
Lighting Level	50-75-100 Fc	16.4 Fc	33.6 Fc (Negative)	Risky
<i>Physical Working Posture</i>				
RULA	1 - 2	7	5 (Negative)	Risky
ManTRA	< 15	16 (Ave. of 4 Body Regions)	1 (Negative)	Risky

Moreover, the researchers intend to identify the significant risk factors affecting the MSDs of the subjects and would serve as the basis for evaluation and development of management plan and improving the current design of the toll booth facility. Based from the results, the identified significant risk factors of MSD were prolonged sitting, physical setup of the workplace, prolonged standing, trunk position, neck position, irregular sleep due to work, and number of rest days. All of these factors being examined were proven to be good predictors of MSDs for having $p < 0.05$. At a significance level, R value was 0.924 which indicated a very strong relationship. The adjusted R^2 resulted to 0.8543 revealing that 85.43 % of the variation was accounted by these risk factors. The variable number of rest days showed a negative correlation to the MSD severity. This implied that as this variable increase, the MSD severity will decrease. For the factors such as prolonged sitting, physical setup of the workplace, prolonged standing, trunk position, neck position, and irregular sleep due to work, it is positively correlated with the severity of MSDs which basically relates that as these variables increase, the severity of MSDs also increases. Moreover, since the value of the R^2 was more than 0.80, this indicated that the variables were good predictors of the severity of MSDs. Residual Analysis plot showed that the residuals are normally distributed and the points are randomly scattered around the line, implying that the points are following the normal distribution, which is what is required when using the Multiple Regression Analysis. Using the SPSS Statistics software, the equation is shown below.

$$Y \text{ (MSD Severity)} = 0.862570 + 0.352752 \text{ (Prolonged Sitting)} + 0.187477 \text{ (Physical Setup of Workplace)} + 0.108490 \text{ (Prolonged Standing)} + 0.154079 \text{ (Trunk Position)} + 0.149452 \text{ (Neck Position)} + 0.060135 \text{ (Irregular Sleep due to Work)} - 0.109922 \text{ (Number of Rest Days)}$$

3.1. Ergonomic Design of Toll Booth

In the study, the measurements and design of the toll booth sliding window, its base height, working table, chair, and footstool needed to be changed and improved to follow the anthropometric data of either the toll tellers or Filipino workers here in the Philippines for recommended dimensions needed to use for future design of the toll booth. The computer terminal, telephone, money tray, authentication and tapping device measurements will be retained. Same as for the concrete curb (gutter) base area wherein the toll booth is installed, its height and horizontal clearances. On the other hand, the overall height, width, and length dimensions of the toll booth remain the same as the original. The placement (positioning) of the working equipment however, will change and improved also in order to minimize reaching, as this was found out as the cause of unusual working posture of the subjects. Hence, the following definitions presented below are for the relative anthropometric elements considered for the design of current toll teller's workstation inside the toll booth. It includes the appropriate gender and population percentile needed to undertake in the design considerations. The table below shows the summary of anthropometric references that will be considered in the ergonomic design of toll booth facility.

Table 5. Summary of Anthropometric References

Toll Booth Workstation Specifications	Anthropometric Data	Percentile	Gender
Working Table Height: Max Min	Standing Elbow Height	95th	Male
		5th	Female
Toll Booth Window Base Height	Standing Elbow Height	50th	Female
Working Table Width	Elbow-to-Elbow Breadth + Functional Forward Reach	95th	Male
		5th	Female
Seat Width	Waist/Hip Breadth	95th	Female
Backrest Width			
Toll Booth Window Overall Height	Functional Forward Reach	95th	Male
Seat Depth	Buttock Popliteal Depth	5th	Female
Seat Height: Max Min	Popliteal Height	95th	Male
		5th	Female
Backrest Height	Shoulder Height (Sitting)	95th	Male
Armrest Height	Sitting Elbow Height	5th	Female
Armrest Length	Forearm-Hand Length	5th	Female
Toll Booth Window Width (One Side)	Elbow-to-Elbow Breadth	95th	Male
Distance Between Armrest			
Toll Booth Window Overall Length	Elbow-to-Elbow Breadth x (2)	95th	Male
Working Table Depth/Leg Clearance	Buttock-Knee Depth	95th	Male
Footrest Width	Foot Breadth, Horizontal	95th	Male
Footrest Length	Foot Length	95th	Male
Footrest Height	Step Height	5th	Female
Chair Footrest Height	Popliteal Height (Max) - Popliteal Height (Min)	95th	Male
		5th	Female
Height of Computer Monitor (Top of Screen Above Floor Surface)	Standing Eye Height	5th	Female

Footrest Specifications	Anthropometric Data	Percentile	Gender
Footrest Lower Part (Width)	Foot Breadth, Horizontal x (2)	95th	Male
Footrest Lower Part (Depth)	Foot Length / (2)	95th	Male
Footrest Lower Part (Height from the Floor)	Step Height	5th	Female
Footrest Higher Part (Width)	Foot Breadth, Horizontal x (2)	95th	Male
Footrest Higher Part (Depth)	Foot Length	95th	Male
Footrest Higher Part (Height from the Floor)	Step Height x (2)	5th	Female

Table 6. Summary of Anthropometric Measurement

Toll Booth	Measurements (cm)
Workstation Specifications	
Working Table Height: Max	112.8
Min	89.0
Working Table Width	107.1
Seat Depth	40.0
Seat Width	42.4
Seat Height: Max	47.0
Min	36.0
Backrest Height	52.0
Backrest Width	42.4
Chair Armrest Height	17.0
Chair Armrest Length	36.0
Distance Between Armrest	48.0
Working Table Depth/Leg Clearance	61.9
Chair Footrest Height (from the Base)	11.0
Toll Booth Window Base Height	96.3
Toll Booth Window Width (One Side)	48.0

Toll Booth Window Overall Length	96.0
Toll Booth Window Overall Height	86.0
Height of Computer Monitor	134.0
Footrest Specifications	Measurements (cm)
Footrest Lower Part (Width)	23.0
Footrest Lower Part (Depth)	14.0
Footrest Lower Part (Height from the Floor)	14.6
Footrest Higher Part (Width)	23.0
Footrest Higher Part (Depth)	28.0
Footrest Higher Part (Height from the Floor)	29.2

3.2. Design of Money Slide/Drop Equipment

In order to lessen the discomfort experienced by each subject from the left portion of the body regions such as shoulder, upper arm, forearm, and wrist/hand, the researcher designed an ergonomic based product that would help bring ease when reaching the toll fee given by the motorists in every transaction. The concept is based on the final output of the study conducted by Seva, Axalan, and Landicho (2011) about workplace efficiency improvement of jeepney drivers in Metro Manila. There are two (2) product designs proposed in the study. These are money slide (adjustable) and money drop (L – shaped) design that should be used for toll booth lane handling different vehicle classes. The location where each of this proposed equipment must be placed is on the outside of the toll tellers working area. An adjustable height of the rectangular box end portion for receiving of toll fee and returning of change and receipt from the motorist to the worker vice versa was considered in product development since the height of the vehicles here in the Philippines and especially those passing thru the expressway are varying. For the toll tellers to use or control the product during transaction, they simply needed to handle its end part and move the rectangular shaped box (receiving box) of this equipment in downward or upward direction to be able to slide the things being put in there and pick it. To the motorist, they will just put the bill in the rectangular shaped box for payment and pick the change and receipt gave by the toll teller after the transaction. From this, it would help to eliminate the problem of extending further the arms of the subjects if there was smaller type of vehicle needed to be served. Same as well for leaning of the toll tellers to the toll booth window that caused awkward posture of their trunk. The anthropometric dimensions for money slide/drop equipment is shown in the table below.

Table 7. Summary of Anthropometric Reference for Money Slide Equipment

Money Slide Specifications	Anthropometric Data	Percentile	Gender
Overall Length	Functional Forward Reach	5th	Female
Overall Width	Hand Breadth	95th	Male
Overall Height			
Toll Fee, Change, & Receipt Receiving Box Depth	Hand Length	95th	Male
End Portion Receiving Box Contour	Hand Circumference	95th	Male
Money Drop Specifications	Anthropometric Data	Percentile	Gender
Receiving Box Overall Length	Hand Length	95th	Male
Receiving Box Overall Width	Hand Breadth	95th	Male
Receiving Box Overall Height			
Top Section Toll Fee Dropping Box Overall Length & Width			

Top Section Toll Fee Dropping Box Overall Height (Vertical Positioned Rectangular Box)	Functional Forward Reach	5th	Female
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3.3. Overall Design of Toll Booth Facility

There are two toll booth design the researcher had been proposed. One is for the class-1 toll booth lane where money slide equipment must be installed outside. The Next design is for the class 2 & 3 toll booth lane where money drop equipment must be installed outside. The images presented below are the perspective and top views of proposed ergonomically designed toll booth made via AutoCAD software.

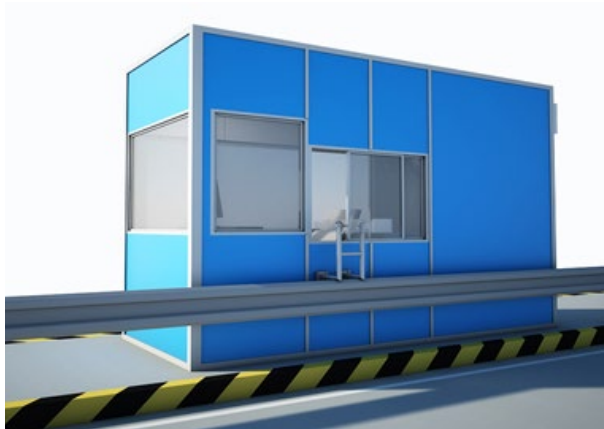


Figure 2. Perspective View of Toll Booth for Class 1 Vehicle Lane



Figure 3. Perspective View of Toll Booth for Class 2 & 3 Vehicle Lane

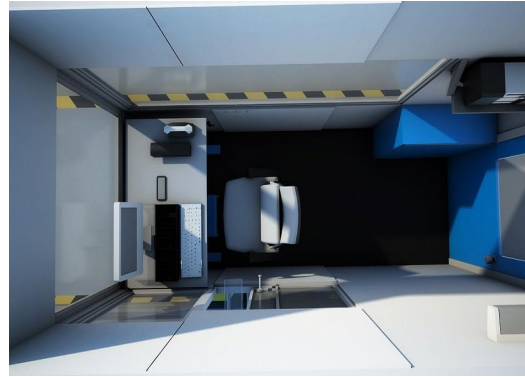


Figure 4. Interior Perspective of Toll Booth Facility

Based from the 3D SSPP software for the evaluation of proposed design, the 'Final RULA Score' of 7 collected from both the current design of class-1 and class 2 & 3 toll booth lane was reduced into scores of 3 and 4 respectively. The proposed design helps minimize exposure to MSDs of the subjects in the workplace, for this had improved the body posture when performing the task, which in case one of the causes for developing this kind of occupational risk. The result of evaluation is shown in the figure below.

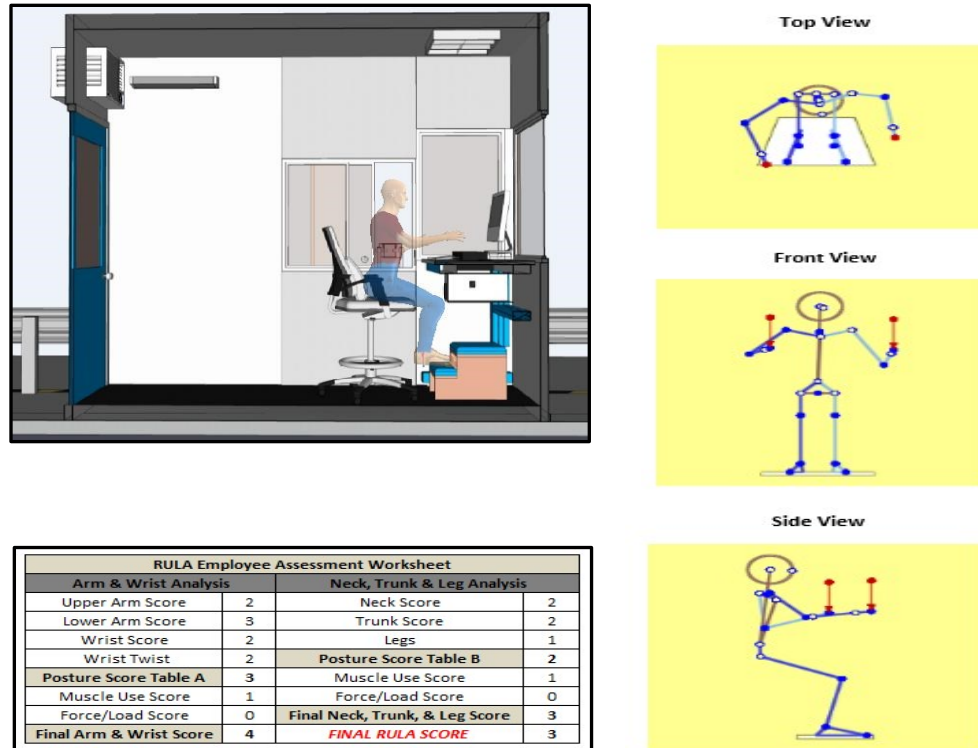


Figure 5. Result of RULA evaluation

4. Conclusion

The study proves that MSDs exist to the current line of work of Filipino toll tellers. Aside from exposure to this kind of occupational risk factors, the toll tellers were prone to the other risks from the different environmental factors (i.e. acoustical, thermal, and visual). Based from the results of ManTRA for toll fee collection task, the subjects were also exposed to repetition and exertion risks. The statistical tool such as Multiple Regression Analysis is a great tool for identifying the contributing factors to the severity of MSDs experienced by the subjects. The recommended design of toll booth can be used as reference material for its construction in the different areas of the Philippines. For this greatly reduced existence of MSDs (Final RULA Score reduced to 3 and 4) and at the same time keeps the workers from the risk of other injuries.

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Biographies

Jenalyn Shigella G. Yandug is a Professor in the School of Industrial Engineering and Engineering Management at the Mapua Institute of Technology. She earned her B.S. in Industrial Engineering and Master in Engineering Program major in Industrial Engineering from Mapua Institute of Technology.

Marvin L. Cruz is a graduate of B.S. in Industrial Engineering at the Mapua Institute of Technology.