Ergonomics Evaluation of Lever-Operated Knapsack Sprayer

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Abstract. The study aims to redesign the classic LOK-sprayer since it is one of the commonly used by Filipino farmers. LOK-sprayer is a knapsack-style hydraulic energy system which is primarily composed of a tank, a pump and a droplet-producing system that are all carried on a person's back. It is used to apply pesticides or other agricultural chemicals. This study intends to ergonomically redesign an existing LOK-sprayer model that will best conform to its functions without sacrificing its operator's comfort. A survey was conducted in order to acquire information essential to the development of an ergonomically designed LOK-sprayer. Descriptive statistics was used to interpret the results of the product evaluation. The researcher came up with one optimum solution with regards to the poor design of a lever-operated knapsack sprayer and the discomfort it brings to its users. The redesigning of a LOK-sprayer was segmented by parts in which each portion of the product was altered in order to give more emphasis to ergonomic principles. The researcher considered the following factors in redesigning the lever-operated knapsack sprayer: (1) tank size and capacity, (2) straps, (3) hose, (4) waist belt, (5) hand lever, and (6) lance/wand.

Keywords: lever-operated knapsack sprayer, tank, hose, ergonomics, lance

1. INTRODUCTION

Agriculture is one of the main sources of living among developing countries such as the Philippines. According to a census done by the Department of Agriculture on 2012, thirty-three percent (33%) of the country's labor force is farmer. Farming is undeniably a very difficult task when we deal with agriculture. It requires tremendous time and effort when farmers plough their fields to ensure the readiness of the soil before planting their crops. But farming does not end in ploughing fields and planting seeds, it continues until farmers gain the fruits of their labor as they reap good harvests. To ensure these good harvests, farmers take very good care of their crops. They provide different maintenance activities just to make sure that their crops grow healthy and robust. Farmers monitor irrigation to sustain good water supply on their fields. They also use different pest-control techniques to prevent loss or damages due to unwanted pests and weeds that may roam in their fields. To perform these tasks, farmers use different farming tools and equipment. One of the most commonly used equipment is the lever-operated knapsack (LOK) sprayer, a tool used for spraying chemicals among plants to prevent harm brought by pests, insects or other plants.

According to Penshin and Dhawan (2009), in the Philippine farm record keeping survey, it was found that farmers applies insecticides with stainless steel, lever-operated knapsack (LOK) sprayers. LOK-sprayer is a knapsack-style hydraulic energy system which is primarily composed of a tank, a pump and a droplet-producing system that are all carried on a person's back. It is a versatile tool, which with appropriate fittings can apply herbicides, pesticides, insecticides and other compounds. It allows application of chemicals nearly anywhere a person can walk, or in areas inaccessible to large, motorized sprayers. It is not a high capital cost tool compared to other farming equipment for it requires minimal maintenance.

On the contrary, LOK-sprayers require a large volume of solution compared to other chemical applicators. According to the International Plant Protection Centre (IPPC) chartered at Oregon State University, Corvallis, Oregon (USA), a LOK-sprayer, when filled with 18 liters of solution can weigh up to 22 kilograms (48 lbs), which is a burden to the person carrying it considering tropical conditions and rough terrain. Moreover, if sloppily maintained or poorly designed and constructed, it might impose hazard to the operator using it as well to other human, animals, crops and to the environment in general.

This study is intended to ergonomically redesign an existing LOK-sprayer model that will best conform to its functions without sacrificing its operator's comfort. The study also aims to produce a LOK-sprayer that is reasonably comfortable to wear and to use while producing satisfactory output at a sustainable human effort.

1.1 Problem Statement

The existing model of a lever-operated knapsack sprayer, which is widely used in rural areas for pest control in the farm, is considered non-ergonomically designed. These LOK-sprayers when filled with 18 liters of chemical solution can weigh up to 22 kg (48 lbs), a substantial burden to the operator carrying the machine considering tropical conditions and rough terrain to traverse (Deutsch, 1985). The survey conducted among one hundred (100) farmers from three (3) different municipalities also reflected problems that deal with the construction and usage of the LOK-sprayers. These are as follows:

- Ninety-four (94) out of one hundred (100) farmers experiences discomfort when using the LOK-sprayers
- Farmers experience discomfort and pain in different parts of their bodies when using the LOK-sprayers. Ninety-seven percent (97%) of the survey respondents experiences discomfort and pain on their shoulders, eighty-six percent (86%) has concern with their back after using the equipment, fifty-seven percent (57%) feels discomfort on their arms, and twenty-eight percent (28%) complains an aching neck.
- Some of the farmers experience numbness of the back because of the frequent bouncing of the sprayer's tank when it becomes lighter as the solution inside decreases.

1.2 Objectives of the Study

The main objective of the study is to ergonomically redesign an existing model of a lever-operated knapsack sprayer that will best conform to its function without sacrificing the comfort of its operator.

1.3 Rationale of the Study

The study was conducted in order to determine variables that can be manipulated that will help the researcher in the development of an ergonomically designed and efficient lever-operated knapsack sprayer. In addition to the latter, the arousal of the study was brought by the researcher's initiative to help their community since most of the researchers live in areas where farming is a common mean of living. The researcher considered the study worthwhile and seasonal since the Philippines is an agricultural country wherein farming equipment is important.

1.4 Scope and Limitation

The study focuses only on the classic lever-operated knapsack sprayer which is a prominent tool of Filipino farmers nowadays. The researcher opted to focus on the classic model, instead of the newer ones available in the market, because most Filipino farmers, especially those who are living in rural areas, consider it simpler to use than the high-end models. The researchers conducted a survey with one hundred (100) farmers, at most, as respondents. These respondents came from Bocaue, Pandi and Sta. Maria, all known agricultural municipalities in Bulacan. The instrument used in the survey consisted of several questions that will identify several factors that are essential in the development of an ergonomically designed LOK-sprayer. The survey ran for almost two weeks which started on the first day of September 2015 and ended on ninth day of the same month and year.

2. METHODOLOGY

2.1 Subjects

The subject for this research is the classic lever-operated knapsack (LOK) sprayer used by most farmers in several municipalities in Bulacan. LOK sprayers were subjected into an evaluation in order to come up with a better design that will conform to ergonomic standards and principle.

2.2 Data Collection

The researcher gathered necessary data for the study though survey technique and made use of questionnaires as instruments. The questionnaire was consisted of seven (7) questions that are all stated in Filipino. The questions used were divided into two types: multiple choice and open-ended.

2.3 Data Analysis

The researcher made use of anthropometry in order to interpret the results of the survey and the random

measurement among farmers from the involved municipalities.

3. RESULTS AND DISCUSSION

After conducting a survey and interpreting the data gathered, the researcher came up with one optimum solution with regards to the poor design of a lever-operated knapsack sprayer and the discomfort it brings to its users. The researcherdecided to redesign the product that will conform to ergonomic principles to increase user satisfaction through elimination of discomfort which the operators experienced when using LOK-sprayers.

The redesigning of a LOK-sprayer was segmented by parts in which each portion of the product was altered in order to give more emphasis to ergonomic principles.

3.1 Increasing of the Tank's Capacity and Size

The tank of a LOK-sprayer normally has dimensions of 16.5 centimeters in width and 45.5 centimeter height and has a capacity of eighteen (18) liters for containing chemical solutions such as pesticides, herbicides and insecticides. It is made of stainless steel which weighs up to twenty-two (22) kilograms or forty-eight (48) pounds (Fisher and Deutsch, 1985).

From the current dimensions of the lever-operated knapsack sprayer, the researcher decided to increase its dimensions and capacity based on two factors that manifested in the survey results.

Figure 1 Present Tank of an LOK-Sprayer

- Farmers do not utilize the current capacity of the LOK-sprayers efficiently because the current dimension of the sprayer is insufficient to accommodate the demand of farmers for chemical solution. Based on the survey, farmers usually use at least one gallon up to six (6) gallons of chemical solution at most which is equivalent to at least twenty-three (23) litres.
- Since the current capacity of the tank is not appropriate to the demand for chemical solution, the dimension of the tank is not also appropriate.

In increasing the tank size, the researcher considered the greatest amount of chemical solution that the sample size used which ranged from five (5) to six (6) gallons which is equivalent to at least twenty-three (23) liters. This assumption for the capacity of the redesigned tank was based on a min-max strategy wherein researcher considered the extreme values in designing a product to ensure that most users with different necessity can utilize it (Salvendy, G., 2012). In the case of this study, the researcher chose to consider the extreme maximum value for the tank's capacity which was based on the data gathered. The researcher used the concept of ratio and proportion in determining the new size of the tank with respect to the present and proposed capacity of the LOK-sprayer tank which is shown by the equation,

Applying the equation and substituting all known values:

$$\frac{PresentTankCapacity}{PresentTankHeight} = \frac{Proposed\ Tank\ Capacity}{Proposed\ Tank\ Height} \quad (1)$$

$$\frac{18\ litres}{45.5\ cm} = \frac{23\ litres}{Proposed\ Tank\ Height}$$

$$\boldsymbol{Proposed\ Tank\ Height = 58.14\ cm}$$

3.2 Introduction of Padded Straps

Based on the survey, ninety-seven (97%) of the respondents complains an aching shoulder after using the LOK-sprayer. This discomfort might be brought by the design of the straps. The current strap design (as shown on Figure 2) though wide enough to distribute the weight of the tank and chemical solution has no padding that causes the strap to dig deep onto the user's shoulders.

From the survey conducted, great number of the respondents complained an aching shoulder after using the LOK-sprayers. This is because of the present design its strap has. As presented on Figure 2, the current strap design for LOK-sprayers is wide and flat. It is observed that no padding is included on the present design. Though wide enough to distribute the load's weight into the shoulders of its operator, these straps, as working time prolongs, tends to dig deep into the skin eventually resulting to numbness or pain.

To resolve this issue, the researcher altered the present strap design for LOK-sprayers. The researcher added padding, which is made of foam, to LOK-sprayer straps. The padding or foam helps reduce the compressive force brought by the load's weight to the shoulders (Grandin, 2011) as it is carried by its operator.

Figure 3 Proposed Strap Design with Foam Padding for LOK-Sprayer

3.3 Hose

The researcher opted to alter the length of the hose because of two reasons, as follows:

- Long hoses tend to dangle when being used by operators with shorter arm length. This dangling hose might hinder the farmer from doing his/her task appropriately since he/she needs to adjust because of the hose's excess length.
- Short hoses tend to put the operator's arm in a bended position especially when the user has a long arm length. Doing a task, such as spraying chemical solution, can be more tiring when the user's arm is at an awkward position which may bring discomfort over long period of time.

In order to develop a hose with an appropriate length, the researcher subjected this factor into statistical anthropometric approach which was based recorded measurement of thirty-six (36) farmers.

To get the arm length of each farmer, the measurement was divided into two segments: (1) shoulder to elbow and (2) elbow to knuckles.

$$Mean\ \ (Arm\ \ Length) = Mean(Shoulder - Elbow) + Mean\ \ (Elbow - Knuckles) \quad (2)$$

$$Mean(ArmLength) = 27.99444444\ \text{cm} + 35.59722222\ \text{cm}$$

$$\underline{\boldsymbol{Mean(ArmLength) = \ 63.59166667\ cm}}$$

length, the researchers applied the formula,

$$SD\ \ (Arm\ \ Length) = SQRT\ \ \{SD(Shoulder - Elbow)\text{^}2 + SD\ \ (Elbow - Knuckles)^2 + \quad (3)$$

By substituting the standard deviation of each segment:

$$SD\ \ (Arm\ \ Length) = SQRT\ \ \{(2.262608412\ \text{cm})\text{^}2 + (2.52422391\ \text{cm})\text{^}2 + [(2)(0.04)(2.262608412\ \text{cm})(2.52422391\ \text{cm})]\}$$

$$\underline{\boldsymbol{SD(Arm\ \ Length) = 4.007513865\ cm}}$$

After the researcher determined the mean and standard deviation of the whole arm length, the researcher determined the 5th and 95th percentile in order to design a hose with appropriate length based on the data gathered through measuring the arm length of a given sample size. The researcher applied the formula,

$$p = m\ \ \pm kSD \quad (4)$$

where:
p is the percentile value
m is mean of data involved
k is the factor for computing percentile values
SD is the standard deviation of data involved

To get the 5th percentile:

$$5p = 63.59166667 \text{ cm} - (1.65 * 4.007513865 \text{ cm})$$

To get the 95th percentile:

$$95p = 63.59166667 \text{ cm} + (1.65 * 4.007513865 \text{ cm})$$

$$\underline{\mathbf{95p = 70.20406454 \text{ cm}}}$$

was approximately seventy (70) centimeters in length. By making the length of the hose seventy centimeters, thirty-three (33) farmers can use the LOK-sprayer's hosecomfortably. Only three (3) out of thirty-six (36) farmers (with arm lengths exceeding 70 centimeters) might experience discomfort making the researcher's adjustment ninety-two percent (92%) effective in terms of comfort in the given sample size.

The researcher based the decision on the individual arm lengths and not on the average or mean of the arm lengths which was computed earlier with a value of 63.59166667 cm. This was based on an ergonomic principle which states that in designing a product, researcher did not consider an average person. The extremes must be considered in order to ensure that more people can use a product comfortably (Kroemer K., Kroemer H. and Kroemer-Elbert K., 2001).

3.4 Addition of a Waist Belt

Aside from painful shoulders, farmers also complained painful backs after a day of work with lever-operated knapsack sprayers. Based on the survey that was conducted, the back ranks second when it comes to body portion that aches or sores after the usage of LOK-sprayers.

Except from the load's weight, pain felt and experienced by farmers after using the LOK-sprayers is brought by the absence of a waist belt on most LOK-sprayer designs. As the spraying process commence, the load's weight carried by the farmer on his back declines because the chemical solution inside the tank is being used up. As this happens, the tank becomes lighter and eventually bounces on its operator's back (Fisher and Deutsch, 1985). Continuous bouncing of the tank brings stress to the farmer's back and when this happens repetitively which may result into cumulative trauma disorders affecting the back or spine of the operator (Kelley, 1995).

Figure 4 Proposed Waist Belt to be added in the Construction of an LOK-Sprayer

To eliminate the risk of acquiring back disorders or other cumulative trauma disorders, the researcher included the placement of a waist belt in their proposed LOK-sprayer design. The waist belt, together with the padded shoulder straps, effectively transfer load weight from the shoulders and off the hips of its operator or user (Grandin 2011). The waist belt also helps the operator anchor the LOK-sprayer on his/her back firmly removing the possibility of bouncing. The waist belt is also padded to ensure comfort on the hip area of the operator.

3.5 Gun-Type Hand Lever

The present design of the LOK-sprayer's hand lever shown in Figure 5 tends to put the operator's wrist at an awkward position (Refer to Figure 6) which on the long run caused stress and pain to the operator's wrist.

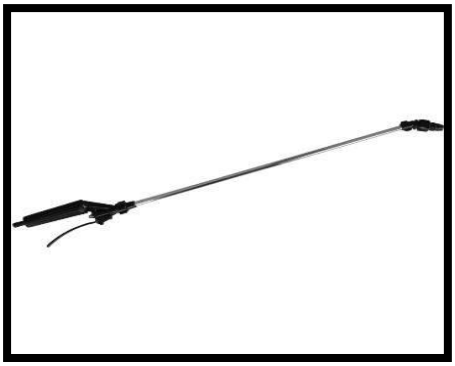

Figure 5 Present Hand-Lever Design of an LOK-Sprayer

Figure 6 Wrist Position offered by the Present Hand-Lever Design of an LOK-Sprayer

The researcher proposed the replacement of the present hand lever into a gun-type hand lever. A gun-type hand lever offers the wrist to at a normal position which will eliminate stress felt by the farmers when using the typical hand lever design. Figures below show the gun-type lever design and the normal wrist position it offers to its user.

Having a gun-type lever for the LOK-sprayer offers the operator to have a normal wrist position compared to the typical hand lever. As prescribed by the guidelines in "Ergonomics Guidelines for Manual Material Handling" published in 2007, workers must be in their normal working position to avoid having cumulative trauma disorders such as tendinitis, tenosynovitis, and trigger finger (Kroemer K., Kroemer H. and Kroemer-Elbert K., 2001).

Figure 7 Proposed Gun-Type Lever Design of an LOK-Sprayer

Figure 8 Wrist Position offered by the Proposed Gun-Type Lever Design of an LOK-Sprayer

3.6 Addition of another Lance/Wand

The survey yielded data that reflected body parts that experienced pain or numbness after using the LOK-sprayer. Among these body parts, arm ranks fourth.

Figure 9 Lance/Wand of an LOK-Sprayer

The present design of the LOK-sprayer consists of only one lance/wand which is dedicated only for the dominant hand of the user because of this; the operator usually uses only one of his arms in spraying chemical solution into the field causing stress to that working arm. In addition to the latter, having a single lance/wand for spraying solution forces the operator to twist his body in order to reach the other side in order to spray the solution as shown on Figure 10.


Figure 10 Normal (Left) and Twisted (Right) Position with a Single Lance/Wand

In order to eliminate the pain experienced by a sole working arm and avoid twisting of the body, the researcher added another lance/wand making it two in the proposed design. Having two lances/wands in the spraying process reduces stress or fatigue experienced by the operators which unlike having only one lance/wand where the operator needs to extend his sole working arm up to a point that exceeds his normal maximum reach causing strain in the involved arm. Together with that, having two lances/wands the operator does not need to twist his body to create full spray coverage as shown in Figure 11.

The addition of another lance/wand intends to eliminate two things: (1) stress experienced a sole working hand because of long working hours, and (2) twisting of the body while carrying a heavy load. Having two lances/wands reduces the risk of acquiring cumulative trauma disorders due to repetitive work (Kelley, 1995) and spinal or back injuries brought by too much twisting while carrying the LOK-sprayer in accordance to guidelines of manual material handling (Kroemer K., Kroemer H. and Kroemer-Elbert K., 2001).


Figure 11 Normal (Left) and Untwisted (Right) Position with Dual Lance/Wand

4. RECOMMENDATION

After interpreting the data gathered and evaluating the alternative/s developed, the researcher decided to redesign the classic lever-operated knapsack (LOK) sprayer in order to conform to ergonomic principles and standards. The researcher decided to initiate a segmented redesigning of the LOK-sprayer wherein each portion of the product was altered in order to give more emphasis to ergonomic principles. The data gathered from the conducted survey manifested results that gave rise to the problem with the present design of LOK-sprayers. The researcher considered the following factors in redesigning the lever-operated knapsack sprayer: (1) tank size and capacity, (2) straps, (3) hose, (4) waist belt, (5) hand lever, and (6) lance/wand.

5. CONCLUSION

The researcher did alterations in order to produce an ergonomically designed sprayer. The researcher increased the tank's size and capacity in order to accommodate the farmer's demand for chemical solutions. Straps were proposed to be padded to lessen the compressive force brought by the load's weight into the operator's shoulders. The length of the hose considered was from the 95^{th} percentile value, which were 70 centimeters at least, that was based on the data gathered when the researcher measured the shoulder-elbow and elbow-knuckle length of thirty-six (36) farmers. A waist belt was proposed to be added into the LOK-sprayer design to avoid bouncing of the tank, as chemical solution inside declines, reducing stress experienced by the operator. The typical hand lever was replaced by a gun-type hand lever to ensure that the

operator's wrist is at a normal position during work to avoid cumulative trauma disorders such as tendinitis, tenosynovitis, and trigger finger. Lastly, the researcher added another lance/wand into the sprayer's construction to ensure balance of work between the operator's arms, on the same hand, to eliminate the tendency of the operator to execute twisting movements. Elimination of twisted movements reduces the risk of having back or spinal injuries. The researcher opted to redesign each part of the lever-operated knapsack sprayer in order to come up with an over-all impact to the users. As each part of the sprayer conforms to ergonomic principles and standards, the LOK-sprayer itself improves in terms of comfort and safety it offers to future users.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my co-faculty members from the Industrial Engineering Department of Bulacan State University for their continuous support to my study. Their expertise in the field and for their patience, motivation, enthusiasm, and immense knowledge are much appreciated. Their guidance helped me a lot with the research and writing of this study.

To my dear friends and colleagues, who willingly gave ideas and suggestions that always answers questions, clarifications in different parts of the study. Those sleepless nights and tiring days with them help the researcher developed a worthwhile and seasonal study.

To the farmers who willingly cooperated during the survey and measurement gathering, answered some of the researchers questions, and gave further suggestions in the development of the product.

For my family who's always there and believe in everything I do, thank you so much.

And finally, to the Almighty God who gives us guidance, strength and knowledge in conducting the study. Without Him this study will be nothing. Everything that the researcher did was for His greater glory.

REFERENCES

Grandin, Matthew, (April 20, 2011). "The Simple Basic Backpack", Michigan,USA.

H.H. Fisher, A.E. Deutsch, (January, 1985). "A Practical Scrutiny and Assessment of Features, Components, and Operation – Implications for purchasers, Users, and Manufacturers", Corvallis, Oregon, USA; pp. 11-32.

Kelley, Kevin D., (December, 1999). "An Ergonomic Evaluation and Analysis for Identifying Cumulative Trauma Exposures in the Office Workplace", Menomonie, Wisconsin; pp. 4-8, 10-11.

Kroemer K., Kroemer H. and Kroemer-Elbert K., (2001). "Ergonomics, How to Design for Ease and Efficiency", 2nd Edition, Pearson Education, Asia Pte Ltd., 2001.

Peshin, Rajinder and Dahwan, Ashok K., (2009). "Integrated Pest Management: Dissemination and Impact", Clemson, South Carolina, USA; pp. 217-218.

Salvendy G., (2012). "Handbook of Human Factors and Ergonomics", 4th Edition, John Wiley & Sons Inc., Hoboken, New Jersey.