Process Improvements of Cilantro Harvesting with Ergonomic Considerations

by

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Executive Summary

The problems presented by Talley Farms to the team were a lower than desired cilantro harvesting capacity and work health pertaining to lower back problems. The project objectives were to address and improve upon both of these objectives. To increase harvesting capacity, a simulation model was created using standard times from time studies. The simulation model helped to compare the different harvesting methods as well as the effect of the utilization of the on-site manager. The throughputs between each of the models were analyzed. To address ergonomic concerns, a work sampling study was conducted and it was determined that kneeling methods are the most ideal ergonomically as they do not require workers to be in the most strenuous positions as compared to the standing methods.

Several conclusions were made based off of the results: harvesting while standing is faster but worse ergonomically and the utilization of a supervisor will increase throughput.

Introduction

The following report covers a process improvement for cilantro harvesting. After identifying the problem and collecting data, the root causes were determined and analyzed for priority. A simulation model was developed in order to see the impact of possible recommendations. A local farm initially approached Cal Poly with several areas of concern for their current operations. Recent policy changes regarding California immigrants and harvesters has led to a labor shortage in the agricultural sector. The current process of cilantro harvesting in particular is accumulating opportunity costs through spoiled crops. In order to solve this problem, the process must be documented and analyzed for appropriate metrics to measure worker efficiency. The DMAIC (Define, Measure, Analyze, Improve, and Control) standard approach to continuous improvement will be used to methodically plan the project. Through data collection and application of industrial engineering techniques, the problem will be addressed and recommendations made to the farm. As part of this project, time studies, simulation, economic analysis, and ergonomics will be considered. The deliverables included in this report include time studies, statistical analysis, working simulation models, ergonomic recommendations and a framework for future improvements. To achieve these objectives, a project timeline was set to track progress. The scope of this project will not include shipping methods or anything past the initial boxing process. Furthermore, because of language barriers and time constraints, improvements will be considered through simulation.

Background

While there has been progress in machine innovation for crop harvesting, many labor processes are still done manually. Crops can lose market value from machine damage due to handling, and often it makes more sense to harvest by hand. Cilantro, a commonly used herb and spice grown predominantly in California, lags the industry in terms of automation. Nearly all cilantro grown in California is harvested through the use of manual labor and represents a majority of the entire cost of production. There have been many studies on the negative effects of manual harvesting on the worker, most looking at how repetitive motions combined with awkward positioning can lead to cumulative injuries.

The United States crop production industry includes roughly one million farms, and they combine for annual revenues of over $225 billion. This huge sector has demand driven by federal agricultural policy programs and food consumption trends. However, there is a huge amount of variability, which leads to many opportunities for quality and process improvements. Although most farms are highly mechanized, manual labor is still used depending on the crop. Large companies have the ability to implement highly automated technology, which generally creates a higher quality environment in terms of product consistency. For this project, the team chose to focus on smaller operations, which have to compete by harvesting specialty products such as non-genetically modified crops, or smaller market products. The difficulties these operations face include seasonal cash flow, environmental threats such as pests and weather, labor shortages, pollution, and dependence on consumer trends.

Herbs and leafy greens are a division of crops that are important for flavor, aroma, and appearance of cuisine. Cilantro is one such group that is used as an herb (cilantro), and

also as a spice (seeds). Cilantro has gained growing global recognition and is widely used in ethnic restaurants such as Mexican and Thai. Most production of this crop is consumed in local markets, due to an inability to preserve the product for long periods of time. California is the largest producer of cilantro in the United States, with the country producing 25.5 million kilograms in 2004, valued at $20.5 million.

Talley Farms is a 1200-acre farm based in the Arroyo Grande Valley. They employ a full-time staff of 100, and harvest six main crops. This senior project will focus on the cilantro harvesting and boxing process. Cilantro is harvested year-round and comprises 25% of the overall acreage. There are two dedicated harvesting teams, which consist of around 12 harvesters and one supervisor.

Current Methods

The flow chart (Figure 1) below shows the overall current process. The scope will cover the cutting, bundling, and boxing processes.

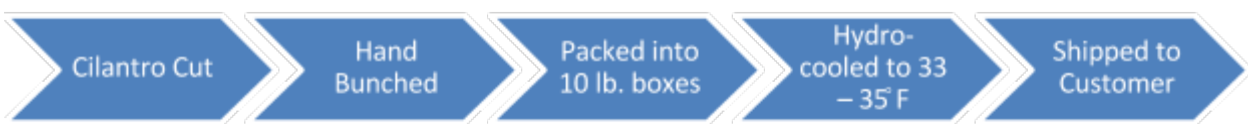

Figure 1: Flow Chart of Current Process

There are three current methods of harvesting cilantro manually. The first method (Method 1) is performed while kneeling; the worker cuts a handful of cilantro, bundles it with a twist-tie, and places the product in a box. After 60 bundles of cilantro are in one box, the box is closed up and the process repeats. This process is illustrated below:

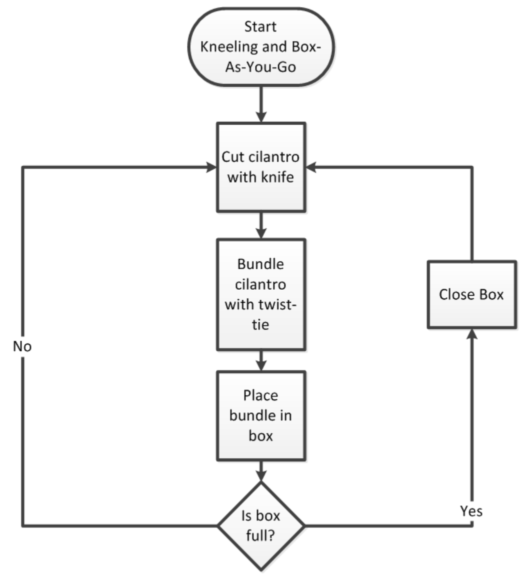

Figure 2: Method 1 (Kneeling and boxing after each cut)

The second method (Method 2) is performed while kneeling, and the worker cuts a bundle of cilantro, bundles, and after accumulating enough cilantro for one box (60-count, or roughly eight yards), boxes the cilantro (Figure 3).

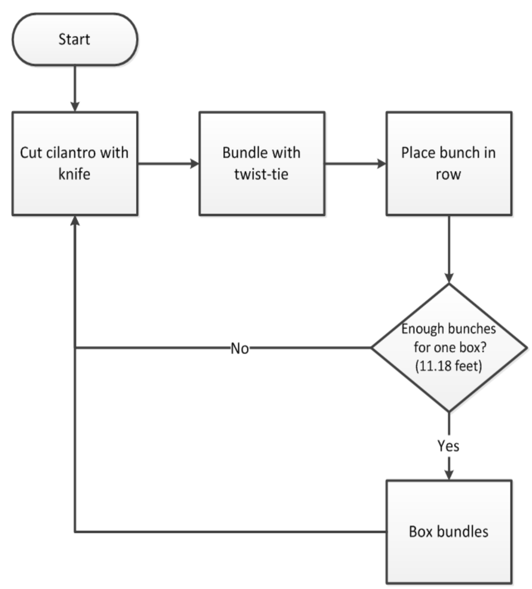

Figure 3: Method 2 and 3 (Kneeling/Standing and boxing after 1-box length)

The third method (Method 3) shares a process flow diagram with Method 2, but the operations are performed while standing. The three methods will be analyzed for differences in speed and ergonomic impacts.

Literature Review

Continuous process improvements and increases in production capacity are integral parts to increasing business profits as well as achieving and maintaining a competitive advantage in the agricultural industry. There are a vast number of ways this can be achieved. This literature review will primarily focus on process improvements and production capacity within the bounds of two industrial engineering areas: human factors and ergonomics, and simulation. Currently, there is a very limited amount of literature and research available related to increasing manual harvesting capacities. While mechanical harvesting innovations are reaching many areas of agriculture, some products are fragile in nature and will lose market value if dropped even a few inches. For other crops, the initial investment on machinery outweighs the benefits.

Ergonomics is defined as "an applied science concerned with designing and arranging things people use so that the people and things interact most efficiently and safely" [1]. Ergonomics is essential because it improves the overall health, safety, and satisfaction of the workforce, which effectively increases productivity [3]. Apart from increased productivity, effective ergonomics will also reduce the number of work related injuries and lower workers compensation costs [3]. In 1999, OSHA estimates that there were approximately 1.8 million work related injuries and illnesses at private businesses

[4]. Also, it is estimated that employers pay between 15 and 18 billion dollars annually in workers compensation costs [4].

Ergonomic Cases

While keeping employee satisfaction high is a priority for most businesses, the ultimate goal is to make more money. A number of studies were found where enhancing employee performance through the use of ergonomics increases productivity. A key step in ergonomic decision-making involves identifying the type of benefits that come with change. Although this seems difficult to estimate benefits in financial terms before a project is undertaken, there are now a large amount of case studies that can support similar endeavors. An electronics plant made changes to the design of fine assembly workstations, which led to a 15% increase in productivity, or a $3,000 per shift increase per worker [5]. An equipment redesign was done in South Africa to change the truck seat height in order to increase visibility. As a result, this company was able to haul one additional load per day, or a total productivity increase of $19,000 per year [5].

Ergonomic Effects

In the manual harvesting of ground level produce, there is a large volume repetitive motions that deal with a work surface that is at an undesirably low height. This presents an ergonomic problem. Musculoskeletal disorders (MSDs), also known as repetitive stress injuries (RSIs) or cumulative trauma disorders (CTDs), are injuries that “are not caused by any singular event, but represent a response of the musculoskeletal systems to cumulative exposure to stresses” [3]. In 2011, MSDs accounted for 33% of all worker injury and illness cases [3] and in 1999, OSHA approximates that there were 582,300 repetitive motion

strains [4]. Lower back injuries account for the majority of MSDs (next to upper limbs) and manual harvesting of ground level produce utilizing repetitive lower back bending motions [3] leaving harvesters likely to be at risk for lower back injuries.

Back, neck, and shoulder strains are common problems among farm field workers. However, there is no specific data pertaining to cilantro harvesting. An ergonomic analysis on an apple harvesting was done in order to study how overall time leads to work injuries. The PATH methodology consists of training the workers in a classroom setting regarding ergonomics, a practice session where data would be recorded, followed by another session with a standard operating procedure in order to correct hazardous motion. During the practice phases, individual data forms were filled out by participating field workers, and the standard operating procedure session was complete only when every participant was on board with the system. Observations were grouped into six specific postures, including three arm positions, two trunk positions, and one leg position. In 45-second intervals, motions were grouped into the posture categories. Each 45-second interval was a single column of data. Activity tasks were summarized in a table with average percentages for each. Another table contained the six body posture positions with percentages of overall time for each. The study concluded by saying that workers in apple orchards spend considerable amounts of time in “awkward” or potentially hazardous positions. The position most detrimental to health was the non-neutral trunk position combined with a weight-bearing load. Over one third of the time in this position “represents significant stress to the back and upper body on a nearly daily basis.” Another awkward position was having one or both elbows up.

The suggested interventions included dispersing some of the load off the upper body coming from the shoulder strap. However, all of the posture-altering interventions slow down the harvest process. It is also noted that while machine harvesting is becoming more prevalent, the "delicate nature of apple harvesting" ensures that hand-harvesting will be an important role in the future.

The work-sampling methodology is useful in collecting statistically significant data even with a small sample of workers. Although the tasks are obviously different than our project, the general steps in ergonomic considerations remain the same. The first is to identify body postures and collect the percentages of times that workers are in these positions. After determining the hazardous or awkward positions, suggestions can be made to place workers in less dangerous positions. Another important note was that all of the suggested posture-altering interventions slowed the pace of the workers. This tradeoff of safety versus speed is an issue that needs to be addressed with the employer and workers [6].

While there is obvious correlation between repetition of movement and cumulative injuries (MSD's), there is little quantitative research to support this. However, there is evidence of torso flexion angle influencing fatigue and repetitions until failure. For example, a study on fatigue failure response of lumbosacral movements looked at the relationship between the flexion posture of the back and movements until failure. The movements were done holding a 9 kg weight, and results showed that the degree of torso flexion had a dramatic impact on cycles to failure. The conclusion showed that fatigue failure of spinal tissues happens much more quickly when the back is at an awkward angle

as opposed to in the neutral position. While thousands of cycles can be tolerated in a neutral position, only a few hundred can be maintained using only a small weight [12].

A study on mandarin pickers concluded that the hard gripping surface of the shears caused pressure and shock vibrations, which in turn caused MSD's. The soft grips of the alternative shears served to reduce these two issues. The pain scores reported by the participants were lower for the soft grip shears, and the pinch strength was higher. Workers spent 15-37% of their time using the shears, leading to high amounts of work injuries. [7] The initial experimentation using ergonomically designed shears lead to a 40% decrease in reported pain, in addition to workers displaying higher peak pinch strength. Another case where a company has implemented ergonomic improvements is with The Boeing Company [8]. Boeing mostly focused "improved workstation design, process reliability, and employee work practices". A decrease in work related injuries and time off work specifically surrounding RSIs, carpal-tunnel syndrome, hernias, and cuts/burns/breaks/etc. were observed. In addition, productivity saw an increase with better quality and lower cycle times.

Although it is difficult to quantify cumulative injuries like MSDs, there have been many studies investigating the risk associated with given processes using posture analysis. A study done on Ergonomic Workplace Design using Novel Ergonomic Postural Assessment Method (NERPA) attempted to determine a new predictive method in order to "make decisions in the design and postural assessment of workstations to reduce the possible risk of experiencing musculoskeletal injuries [14]. The study addresses a major issue analysts find when conducting posture assessments: observer error. While video analysis can be done to minimize mistakes made by observers, this is often costly and time-intensive. By

conducting a proper work-sampling, a necessary sample size can be calculated in order to gain statistically significant results. Additionally, the sampling must be done over a long period and taken at random times, on random individuals. The study went on to discuss the difficulties with quantifying ergonomic data to determine financial costs. There are no conclusive studies to date showing that spending a considerable amount of time in a given position will result in injury a certain percentage of time. The reason for this shortcoming is the variety of factors that impact worker health, such as age, sex, body type, environmental conditions, and more. The complication associated with quantifying cumulative injuries such as MSDs arises when companies ask for economic justification. While there are accepted NIOSH equations for lifting heavy objects given arm position and repetitions, there are no standards for low weight repetitive movements. However, there have been a number of studies that have shown awkward, or non-neutral positions can lead to exponentially lower cycles until failure for repetitive processes (14). The figure (Figure 4) below illustrates this point perfectly showing the cycles until failure for various posture positions lifting a small amount of weight (5 pounds).

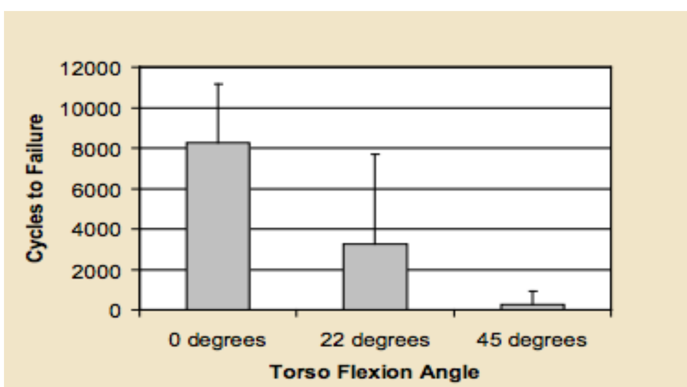

Figure 4: Cycles to failure at varying torso flexion angles

The main conclusion drawn from this study is that there is historical evidence that strongly suggests non-neutral positions can lead to injury over time [14] given the number of injuries reported that are non-acute (no specific instance for injury) in various industries. Any attempt to calculate the economic impact of MSDs by showing certain positions lead to a determined rate of injury and therefore time lost are merely speculation. To prevent these long-term injuries, companies can take steps to reduce the environmental impact on the worker through the use of ergonomics.

Simulation Review

Simulation is defined as “the imitative representation of the functioning of one system or process by means of the functioning of another” [Merriam-Webster 2014]. The application of simulation is to “define a problem and then build a model from the varying characteristics important to solving the problem” [9]. Simulation can be used to model and/or make improvements in the areas of engineering design, planning, and operations [9]. It can be applied into three different functional areas: evaluation of alternatives, developing alternatives, and selecting alternatives [9]. Using simulation models is useful when evaluating and developing alternatives because it allows the user to compare the outputs of multiple systems based on the desired performance metrics pertaining to the success of the systems.

In one study, simulation was used in order to test the effectiveness and performance of two different in-band sensing and transmission methods for secondary users in cognitive radio networks [10]. In cognitive radio networks, the goal of the secondary user is used to utilize primary user idle times while avoiding interferences with busy periods of the primary user. The study analyzed two parameter policies, fixed and dynamic, determined

by theoretical research and calculations. Several methods were used to determine the parameters for the two different parameter policies: proposed method (determined from theoretical research and calculations), maximum-physical-throughput method (chooses the parameters that produce the highest throughput while limiting the primary user busy period interferences to below a pre-determined level), and maximum-sensing-efficiency method (chooses the parameters that produce the highest throughput to primary user busy period interferences ratio). The maximum-physical-throughput and maximum-sensing-efficiency methods choose their respective optimal parameters through iterative simulations using different parameters. After analyzing the associated data outputs, it was determined that using the proposed method with the dynamic parameter policy was the best performing combination. In this study, simulation was used in evaluating and selecting the best alternative with respects to engineering design and operations.

Another study used simulation to analyze personnel capacity requirements of an equipment maintenance department [11]. Three variable input parameters were analyzed: personnel exchangeability (ability to work between different groups), personnel flexibility (ability to work on tasks differing from their qualifications), and personnel quantity (number of personnel). These input parameters were adjusted in order to produce three output statistics: throughput time, equipment downtime, and capacity utilization. Simulations were carried out using SIMPLE++ and test results were analyzed using sensitivity analysis, specifically one-factor-at-a-time analysis (OFAT). In the end it was found that personnel exchangeability, followed by personnel flexibility, had the most significant effect on all three output statistics. This study used simulation to evaluate operations alternatives.

Simulation has also expanded to the agricultural industry. Having found that harvesting is the largest cost of production [13], a number of studies have looked at streamlining the harvesting process. One study looked at optimizing the number of workers and machines for harvesting cherries while still maintaining a high quality product. The process was modeled and alternative solutions and iterations were compared to find the best practices. If a group consisted of 20 workers, the average wait time would is increased by 34%, while if the group is reduced to 18 workers, the probability that there will be zero workers in the queue rises to 86%. Simulation allows managers to further explore changes in their current system and compare subsequent impacts on cost and worker utilization. The results showed how creating an accurate simulation model can efficiently compare processes to determine the optimal solution.

Design

The design of this project was carried out using a Six Sigma approach, DMAIC (Define, Measure, Analyze, Improve, Control), which is the ideal methodology for improving upon existing business processes. The main problems existing in the current process are labor shortages and the opportunity costs associated with limited harvesting capacity, as well as poor ergonomic conditions for the workers. The aim of this project is to provide throughput and ergonomic analyses for the different harvesting methods and combinations of the different harvesting methods that can be used to determine the best course of action that will be the most beneficial for Talley Farms and its employees.

Metrics

The first step is to measure the throughput of the current process. This was done by performing a time study (Appendix A). Standard times were calculated by incorporating allowances (Figure 5)

Allowance Type	Allowance Percentage
Personal	5%
Basic Fatigue	4%
Standing	2%
Abnormal Position (Very Awkward)	7%
Weight Lifted (10 lbs)	1%
Monotony (High)	4%
Total Allowance	23%

Figure 5: Allowances

Given that there are different harvesting methods, the times were normalized by combining times of steps in the process based on the end product. The end product being one full box of harvested and bundled cilantro. In method 1, this is simply the time between completion of a box to the completion of the next box. In methods 2 and 3, this is the sum of the time to harvest an approximate box amount of cilantro and the time to box that amount of cilantro (See Figure 6).

$$\text{Full Box of Bundled Cilantro} = \text{Box Length of Cut Cilantro} + \text{Package Box Length of Cut and Bundled Cilantro}$$

Figure 6: Equation for time study

It is necessary to take two separate time segments for methods 2 and 3 due to the fact that sometimes the workers will harvest more or less than a box amount of cilantro before boxing. This time study will serve as the basis for analyzing the difference between the different harvesting methods.

The data from the time study for each gathered time segment was fit to a distribution using statistical software, MiniTab. All of the distributions were determined to be normal distributions.

Ergonomic Design

The next step is to analyze the ergonomic effects of each of the different methods. While some methods might increase throughput, they may be outweighed by the negative effects on worker health. To analyze the ergonomics, a work sampling study was conducted. A preliminary investigation to determine the action that carried the most significant risk was conducted. The fish-bone diagram below (Figure 7) illustrates the possible causes for detrimental health effects on manual harvesters.

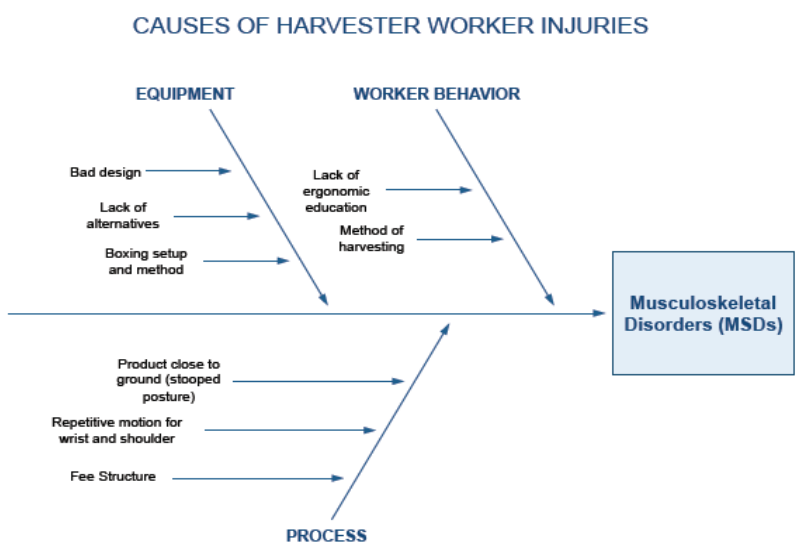

Figure 7: Fishbone Diagram for MSDs

After combining the root-cause analysis with information learned from the literature review, the predominant factor associated with worker injuries involved awkward positioning while performing actions, most notably the flexion angle of the back. While traditional work sampling methods document the percentage of overall time spent doing certain actions, this study was used to measure and estimate the amount of time workers spent in varying posture positions. There were four different positions that were measured in the study (Figure 8): (A) less than 30°, (B) between 30 and 60°, © between 60 and 90°, and (D) greater than 90°.

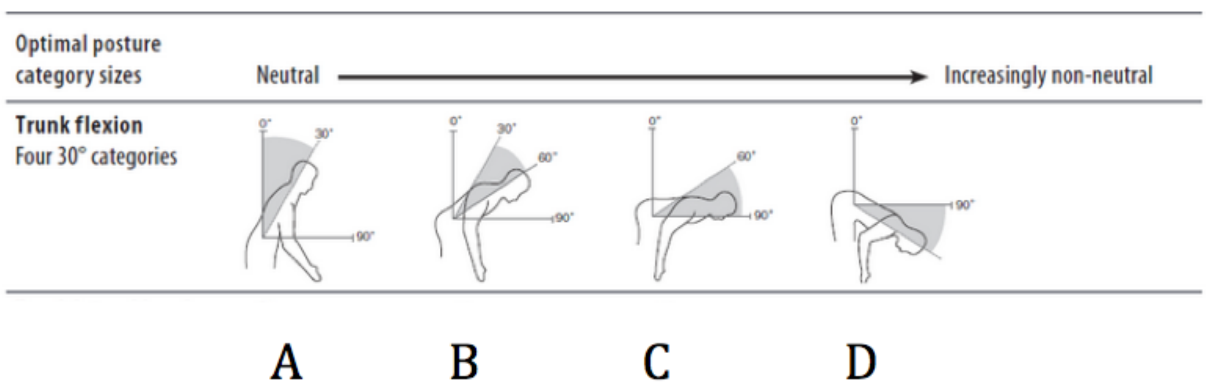

Figure 8: Posture positions for work sampling based on trunk flexion angle

Time spent with extreme bent back angles has been shown to correlate with MSDs and RSIs. The scope of ergonomic analysis was therefore focused on trunk flexion angle in the straight-on position due to the nature of the cilantro harvesting process.

After analyzing the results of the time study and work sampling study, as well as observational accounts of the current process, several alternatives were generated. Alternatives consisted of 12 workers (average amount of workers witnessed) and 1 supervisor. Differences between alternatives consisted of different combinations of

harvesting methods as well as the utilization of the supervisor as a “designated boxer”. In alternatives with the supervisor as a “designated boxer”, workers no longer box their own bundled cilantro. Instead, the supervisor does all the boxing.

Alternative	Number of Workers			Supervisor as “Designated Boxer”
	Method 1	Method 2	Method 3	
1	12	-	-	No
2	-	12	-	No
3	-	-	12	No
4*	8	2	2	Yes
5	-	12	-	Yes
6	-	-	12	Yes

*Alternative 4 uses the current distribution of methods used

Table 1: Alternatives Table

Methodology

Work Sampling

To determine the ergonomic impact of the cilantro harvesting process, work sampling was used. The work sampling procedure can be summarized in five steps:

1. Take a preliminary sample to obtain estimates of parameter values
2. Compute the sample size required
3. Prepare a schedule for random observations at appropriate times
4. Observe and record worker activities
5. Determine how workers spend their time

The work sampling procedure was modified to fit the project by observing and recording worker trunk flexion posture positions (Figure 8) in order to determine how much time workers spend in each position. The necessary sample size for a 5% acceptable level of error was calculated using the equation in Figure 9 below:

$$n = \frac{z^2\, p(1 - p)}{h^2}$$

where

- n = required sample size
- z = standard normal deviate for desired confidence level
- p = estimated value of sample proportion
- h = acceptable error level in percent

Figure 9: Equation for sample size of work sampling

After initial observation, the estimated value of the sample proportion spent in position D was .55. Position D was targeted as defined as “awkward” or “non-neutral” to be most at rist for injury. The required sample size for a 5% error was then calculated to be 380 observations. Below, Figure 10 shows the data collection sheet used:

Observer: Branden
Date:

Observational Posture Assessment

Time:_______
Location:_______

Obs.	ID	Time	Position(ABCD)	Action	
1	12	7:10	D	Bunching	
2	9	7:11	D	Bunching	
3	6	7:23	D	Bunching	
4	7	7:24	D	Bunching	
5	11	7:25	A	Sharpening Knife	
6	11	7:26	D	Bunching	
7	9	7:34	B	Kneeling	K
8	11	7:38	D	Bunching	K
9	5	7:47	A	Resting	K
10	1	8:05	B	Boxing	K
11	3	8:09	B	Boxing	S
12	5	8:16	C	Boxing	S
13	3	8:19	A	Boxing	S
14	3	8:19	C	Boxing	S
15	10	8:32	D	Boxing	S
16	1	8:32	C	Bunching	S
17	11	8:43	A	Resting	S
18	1	8:46	B	Bunching	S
19	2	8:47	C	Bunching	
20	10	8:48	A	Resting	
21	3	9:01	C	Bunching	
22	4	9:01	C	Bunching	
23	7	9:05	D	Bunching	
24	5	9:10	D	Bunching	
25	7	9:12	D	Boxing	
26	12	9:14	D	Bunching	
27	2	9:16	A	Boxing	
28	10	9:24	D	Bunching	
29	9	9:33	D	Bunching	
30	3	9:34	B	Bunching	
31	8	9:41	A	Resting	
32	6	9:49	C	Bunching	
33	11	9:53	D	Boxing	
34	1	9:56	B	Bunching	
35	11	9:59	D	Bunching	

Position A B C D

ID	Characteristic
1	Yellow gray
2	Yellow blue
3	Green overalls
4	Red hat
5	Blue sweater
6	All black
7	Red and Jeans
8	Green Hat
9	Raiders
10	Backwards hat
11	Yellow Black
12	Grey Hat
13	_______________

Totals			
	A	7	20.00%
	B	6	17.14%
	C	7	20.00%
	D	15	42.86%
	Total	35	
Standing			
	A	5	21.74%
	B	1	4.35%
	C	2	8.70%
	D	15	65.22%
Kneeling			
	A	2	16.67%
	B	5	41.67%
	C	5	41.67%
	D	0	0.00%

Figure 10: Work Sampling Data Collection Sheet

On available days, a time block was set between the harvesting hours. Random times were generated, and based on the number of workers on a given day, identification numbers were assigned and randomly paired with a time to record observations. The methods were grouped as kneeling or standing. At a given randomly generated time and worker to observe, the posture was recorded as classified in Figure 8 above, either A, B, C, or D. The observer also noted the worker action at the given time.

Simulation Methodology

To test the effect on throughput for the different alternatives, simulation models were constructed using Simio Simulation Software. Models were constructed for each of the six alternatives as well as for the current model. The current model was used as a baseline for comparison with the alternative models. In all models, the source was given an arbitrarily short inter-arrival time, to simulate the theoretically infinite amount of un-harvested cilantro. Workers using method 1 were simulated using a single server with a processing time equal to the standard time determined from the time study (See Appendix A). Entities, or boxes of cilantro, can only be processed when there is a worker available. In other words, 12 entities are processed at all times.

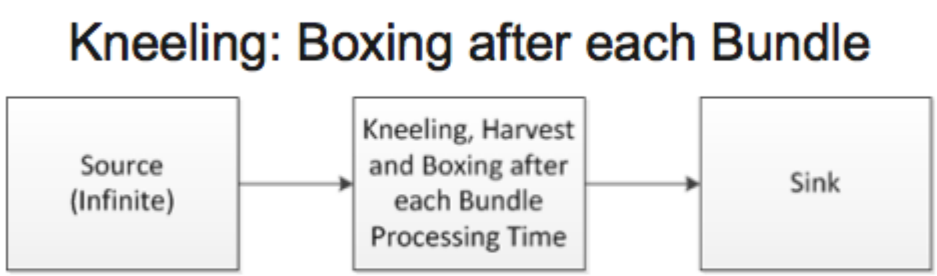

Figure 11

Workers using methods 2 and 3 were simulated using two servers with processing times equal to the standard times to harvest and the time to box as also determined from the time study. Again, entities can only be processed when there is a worker available.

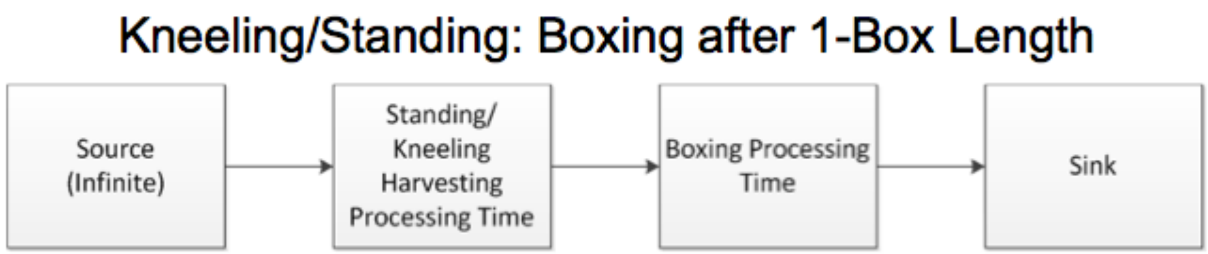

Figure 12

In alternatives where the supervisor was utilized as a “designated boxer”, only when the supervisor was available, could an entity be processed through the boxing server. Whereas, the number of entities being processed through the harvesting server is still equal to the number of workers (12).

For method 1 servers, the processing time was equal to the standard time between completed boxes of cilantro. For method 2 and 3 harvesting servers, the processing time was equal to the standard time to cut and bundle an approximate box worth of cilantro. For method 2 and 3 boxing servers, determining the processing time was slightly more complicated. Since workers might harvest more or less than a box worth of cilantro before boxing, leftover bundles may be present or a box may be left incomplete before returning to cutting. To account for this, boxing server processing times were generated as a function (proportion) of the respective harvesting server processing times. In other words, the time it takes to box was determined by the amount of cilantro harvested for that box. The proportion was generated using Monte Carlo Simulation. For methods 2 and 3, average standard harvesting times were generated alongside

average standard boxing times and the proportion was taken. This was done for 1000 rows. The average proportion and average proportion standard deviation were calculated (Xbar and Sxbar). This was done 10 times and the average of these values were calculated and used in the simulation (xbarbar and sxbar-bar)

$$Processing\ Time_{Boxing} = Processing\ Time_{Harvesting} * \beta$$
$$Where,$$
$$\beta = \frac{Normal\ (\bar{X}_{Boxing}, \bar{S}_{Boxing})}{Normal\ (\bar{X}_{Harvesting}, \bar{S}_{Harvesting}) + Normal\ (\bar{X}_{Boxing}, \bar{S}_{Boxing})}$$
$$\beta \sim Normal\ (\bar{\beta}, S_{\beta})$$

Figure 13: Boxing Processing Time Calculation

Once all of the necessary parameters were calculated in input into the model, a controlled experiment was run. The experiment length was 4 hours (average working time estimate provided by production manager) with 50 replications.

Results

The results of this project are summarized in Table 2 below.

Results & Recommendations

	Standing, Utilize Manager	Standing, 1-Box Length	Current*, Utilize Manager	Current*	Kneeling, Utilize Manager	Kneeling, 1-Box Length	Kneeling, Box Each Bundle
Throughput	+12.4%	+8.5%	+5.6%	-	-9.4%	-13.5%	-21.0%
Annual Revenue	$180K to $675K	$123K to $462	$81K to $303K	-	($136K) to ($511K)	($196K) to ($734K)	($114K) to ($305K)
Ergonomics			-	-			

*Current Method includes:
8 standing harvesters boxing after 1 box length
2 kneeling harvesters boxing after 1 box length
2 kneeling harvesters boxing after each bundle

Table 2: Summary of Results

The results of this experiment were, for the most part, expected. However, there were still some surprises. The standing methods were expected to produce higher throughput than the kneeling methods, however, it was expected that the benefit of utilizing the supervisor would outweigh the cost of the kneeling harvesting method. The ergonomic considerations were as expected. From initial observation, it seemed that harvesting while standing would be much harder on the workers' lower backs.

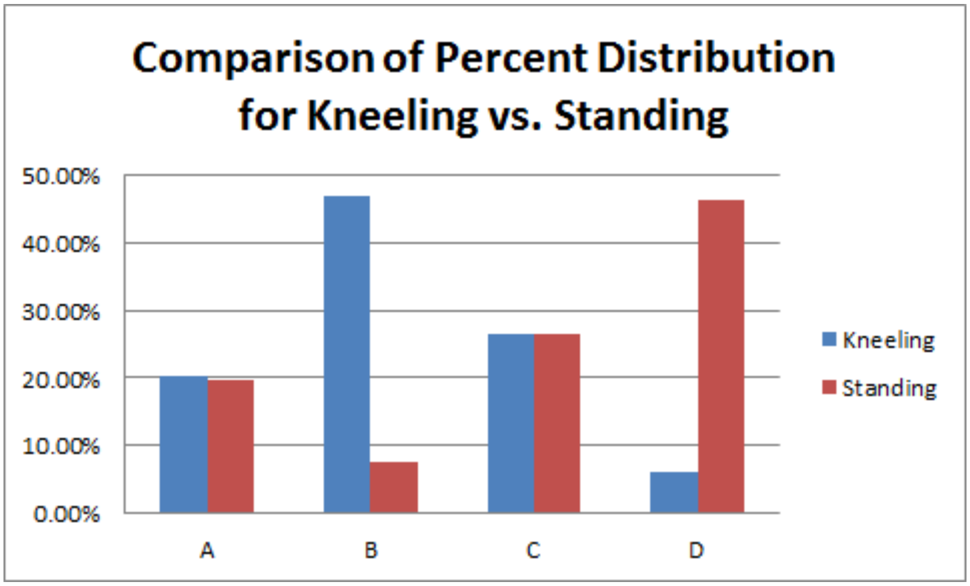

Figure 14: Frequency Distribution for Posture

The chart shows that workers harvesting while standing spend 7.5x in the D position compared to kneeling. Additionally, the standing and kneeling spend roughly the same amount of time in positions A and C. These findings illustrate the inherent danger of the standing harvesting method. The economic impact of the ergonomic analysis was limited by the data obtained from Talley Farms regarding worker absence due to injury. The workers are paid on a per-box rate, and while it has been proven that 37-50% of workers experience MSDs, daily attendance of workers was not tracked. Without this information, the correlation between at-risk postures and lost time due to injury was unable to be quantitated. Below, Table 3 lays out a framework for continuous ergonomic improvement:

Ergonomic Aspect	Suggested Action
Lost time days	Track worker attendance per day to compare method of harvesting with lost time days
Fatigue due to repetitive motion	Allow time for periodic breaks beyond mandated 30 minutes off for every 5 hours of work
Worker Input	Provide means of gathering worker input on current processes (see Appendix D) using an employee suggestion form
Performance Review	Review performance of individual workers by gathering number of boxes harvested per month

Table 3: Ergonomic Continuous Improvement Framework

The obvious limitation for Talley Farms for providing a means for employee suggestion is the language barrier of farm workers. A more informal approach could also be used to gather valuable employee input through the harvesting team supervisor.

One area of our results that would benefit from further investigation would be the difference in annual revenue amounts. The team was unable to obtain concrete historical data on sales prices and was limited to an estimate (prices fluctuate heavily and range from $8-30 per box of cilantro) provided by Talley Farms. Difference in revenue was calculated by providing an upper estimate and lower estimate calculated using the $8-30 price range. Difference in throughput was calculated by simply comparing the throughput of the given alternative to the throughput of the current method.

It would also be beneficial to consider cost, and therefore profit. Unfortunately the team was unable to obtain concrete figures pertaining to the cost of each box. Also, it would be beneficial to quantify the economic impact of the different harvesting methods based on ergonomics.

Assumptions

There were several assumptions made in the analysis of this process:

1. The supervisor rarely has duties (supervisor was not witnessed carrying out any duties).
2. Workers are of equal skill level. Workers all had their methods of harvesting and were observed doing so. No workers were asked to change methods
3. All workers take equal breaks.

Conclusion

The problems presented by Talley Farms to the team were a lower than desired cilantro harvesting capacity and work health pertaining to lower back problems. The project objectives were to address and improve upon both of these objectives. To increase harvesting capacity, a simulation model was created using standard times from time studies. The simulation model helped to compare the different harvesting methods as well as the effect of the utilization of the on-site manager. The throughputs between each of the models were analyzed. To address ergonomic concerns, a work sampling study was conducted and it was determined that kneeling methods are the most ideal ergonomically as they do not require workers to be in the most strenuous positions as compared to the standing methods.

The team was able to make several conclusions based off of the results:

1. Harvesting while standing will have a higher throughput than harvesting while kneeling
2. Utilization of a supervisor will increase throughput regardless of harvesting method

3. Harvesting while kneeling is better ergonomically
4. If harvesting while kneeling, boxing should not be done continuously

Before making a decision on the best harvesting method, Talley Farms must consider the tradeoff between increased throughput and lessened ergonomics, and vice versa. Talley Farms must also incorporate cost per box harvest. However, without these considerations, the team recommends utilizing the on-site supervisor to increase throughput. The choice between switching between kneeling and standing methods requires the aforementioned considerations, however, it is clear that method 1 has a lower throughput and equal ergonomics compared to method 2. Therefore, the team also recommends that workers who harvest on their knees box after a box length of cilantro has been cut and bundled as opposed to continuously.

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Appendix

A: Time study data collection sheet

			Operator											
			Worker 1	Worker 2	Worker 3	Worker 4	Worker 5	Worker 6	Worker 7	Worker 8	Worker 9	Worker 10	Worker 11	Worker 12
Observation	1	R												
		T												
	2	R												
		T												
	3	R												
		T												
	4	R												
		T												
	5	R												
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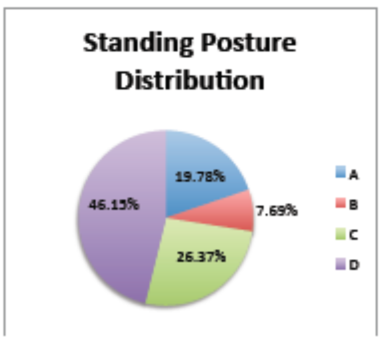
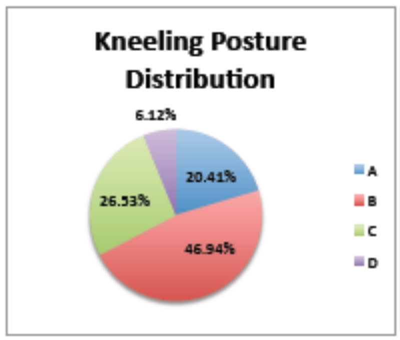
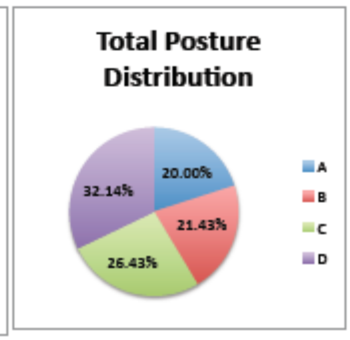
	18	R												
		T												
	19	R												
		T												
	20	R												
		T												
		R												
	Totals	Average OT												
		Average R												
		Average NT												
		Allowance												
		Average ST												

Appendix B: Total Frequencies for Posture Distribution

Standing		
A	18	19.78%
B	7	7.69%
C	24	26.37%
D	42	46.15%
Total	91	
Kneeling		
A	10	20.41%
B	23	46.94%
C	13	26.53%
D	3	6.12%
Total	49	
Totals		
A	28	20.00%
B	30	21.43%
C	37	26.43%
D	45	32.14%
Total	140	







Appendix C: Comparison of Posture Frequencies by Standing vs. Kneeling

Type	Kneeling	Standing	Weighted Average
A	20.41%	19.78%	20.00%
B	46.94%	7.69%	21.43%
C	26.53%	26.37%	26.43%
D	6.12%	**46.15%**	**32.14%**

Appendix D: Sample Employee Feedback From

EMPLOYEE IDENTIFICATION

Full Name: ______________________ Employee #: ______________________

Station Location: ________ Dept: ____________ Phone #: ____________ Mail Code: __________

Position Title: ______________________ Supervisors Name: ______________________

SUGGESTION TOPIC: ______________________

I Believe This Suggestion Will: (check all that apply)

- ☐ Improve Productivity/Quality
- ☐ Improve Safety
- ☐ Improve Equipment
- ☐ Improve Methods/Procedures
- ☐ Save Cost
- ☐ Substitution of Mat. For Improvement
- ☐ Other (explain) ______________________

Description of Problem: ______________________

(Attach additional pages if necessary to provide a full detailed explanation)

Description of Proposed Solution: ______________________

(Attach examples, photos, etc., as needed to explain)

Detail of Cost/Benefits: ______________________

(Attach additional analysis, reference material, etc., as needed to explain)

In consideration for the Suggestion Committee's approval of my suggestion and tender of an award to me in accordance with the Employee Suggestion Program, I agree to assign all my rights, title and interest in and to my suggestion to ABX, and execute all documents and do all that is necessary to assist ABX, at its expense, in obtaining protection therefore including patent, trademark, copyright, mask work and trade secret protection or other form of protection throughout the world.

Employee Signature: ______________________ Date: ____________