Measurement and Design of Work

Work Methods Analysis for Bagel Preparation

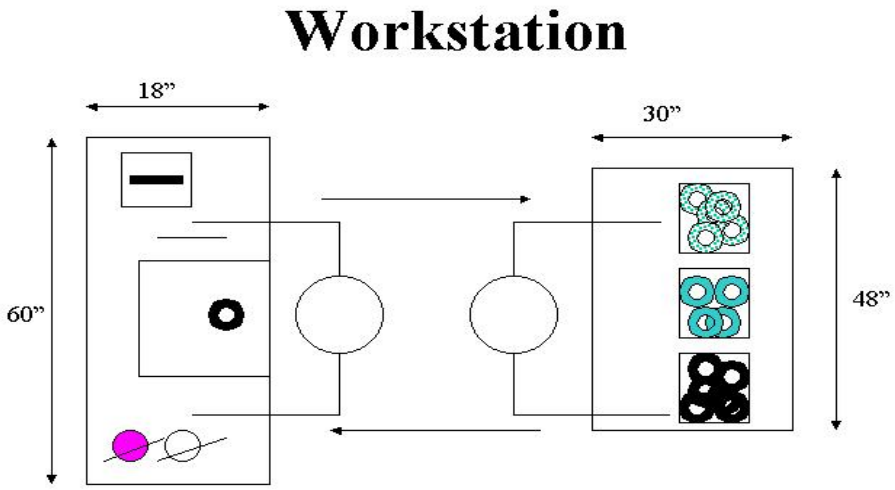
INTRODUCTION

The objective of this experiment was to observe the human-machine system and the work methods utilized in a simulated bagel retail setting in order to identify wasted motions and make a proposal for more efficient operations based on this analysis. In the observed operation, the employee (main test subject) would be taking orders, selecting the bagel, cutting the bagel, preparing it with cream cheese at the customer's request, and delivering it to the customer. In this simulation, currency was not directly exchanged, though the customers placed an imitation currency on the table when placing orders, which served functionally as a consent form for video taping the experiment.

HUMAN MACHINE SYSTEM

Although the main components of this study were the actual motions utilized by each hand of the test subject, the results of these motions were to be analyzed in the context of the entire human-machine system in order to determine the effects of the motions. Thus, it is important to be aware of the structure of the human-machine system for this experiment.

Figure 1: Workstation



In order to obtain a clear understanding of the human-machine system, it is important to break down the specific attributes of each of the main categories in the system for this particular experiment, which is performed in the following table (Table 1.)

Table 1: Work Station and equipment dimensions

Objective: Take the order from the customer, in which he / she requests one of 3 different types of bagel; retrieve this bagel; cut the bagel into 2 halves; ask customer if he / she would like cream cheese, and if so, whether prefer regular or strawberry; load this type of cream cheese on the butter knife and apply this cheese to bagel; put halves together and present to customer.

Work Station:

Machine attributes

1.) Table 1 (right table on depiction), which was used for storing the bagels, was 34" high, had a rectangular surface (48" width x 30" length,) and was flush against the wall on the right.
2.) Table 2 (left table on depiction), which was used for cutting and applying cream cheese, was 29" high, had a rectangular surface (60" width x 18" length,) and was located 58" from the wall on the right.
3.) Three knives were used in the operation: cutting knife size was comparable to U.S. standard kitchen knife; two butter knives (1 for each type of cream cheese) were used, each one of standard U.S. kitchen knife size.
4.) Two containers of different types of cream cheese were utilized, each one of approx 3" in diameter, 2" in height.
5.) Paper sheets (approx 8" x 11") were utilized for presentation to customers; sheets were stored in box that dispensed them (one at a time.)
6.) Three grocery bags (12"w x 7"l x 14"h) containing three different kinds of bagels were located on Table 1, situated 5" from both x-axis table borders and 11.5" from both y-axis borders, with 1" separating each bag.

Human attributes

1.) Employee must fall within height range that allows for large enough work envelope to use appendages comfortably and without strain on table surfaces.
2.) Sufficient wrist strength to cut through multiple bagels (approx 2-3 per minute.)
3.) Sufficient dexterity to hold bagel and cut; hold cream cheese container and load cream cheese onto knife; hold bagel and spread cream cheese on bagel.
4.) Ability to hear orders and feedback from customer.
5.) Ability to see and distinguish types of bagels and cream cheese; see and determine the center of the bagel in order to make proper cut.
6.) Cognitive awareness to maintain quality, safety, productivity and cordiality amidst potential customer cue buildup and complaints (this skill may be more prevalent in employees with experience in food service industry.)

Environment attributes

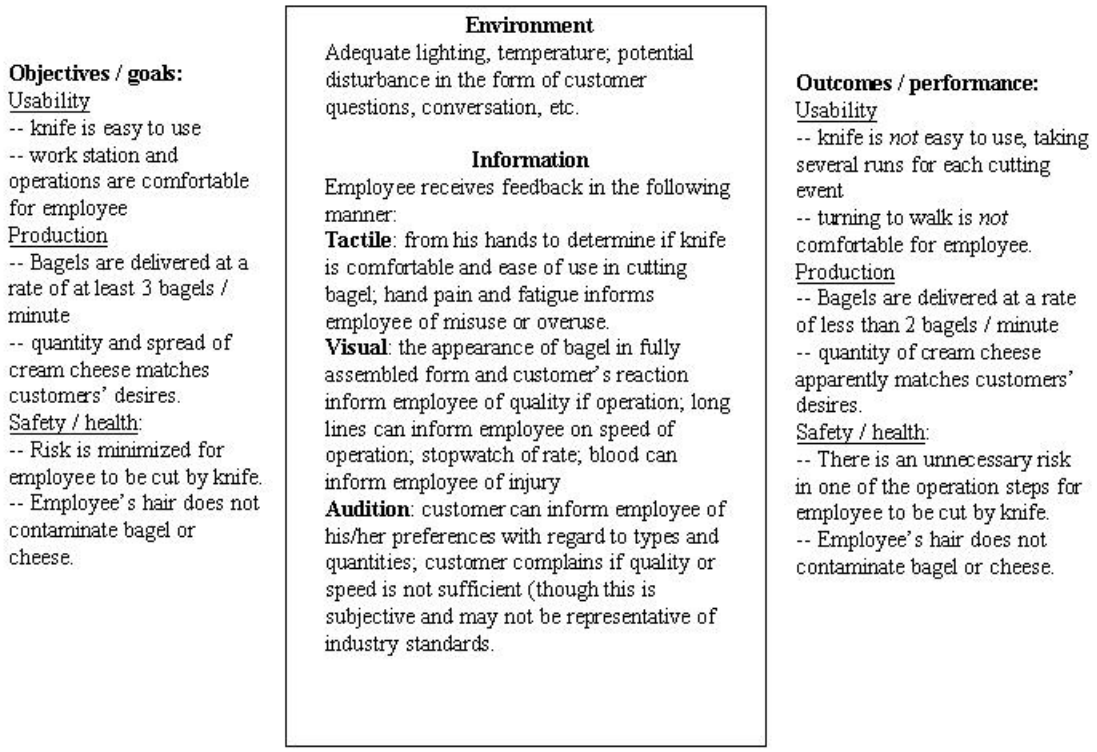
1.) Although there is some customer feedback designed into the operation (selection of bagel and cream cheese type), excessive feedback is a potential attribute that is unpredictable and may cause delays in the operations.

Average rate: Bagels should be produced at the rate of at least 3 bagels / minute.

It is important to understand several aspects about Table 1 as it relates to this particular experiment. With regard to the human attributes, the test subject in this experiment was a male, 6'2" and 195 lbs, with some experience in food service industry. With regard to environmental factors, it is important to note that although in the long run, attributes such as temperature and humidity will be taken into account with regard to bagel storage and freshness, because this analysis has a smaller timescale scope, and is focused on the operations of bagel preparation, these attributes will not play a role in the analysis.

Below is a graphical representation of the human-machine system:

Figure 2: Human-machine system



TEST PLAN

The test subject was instructed to take orders from the customers and perform the tasks described above. No specific goal-oriented instructions were given, as whether to focus primarily on delivering quality bagels with cream cheese spread evenly and plentifully, to deliver bagels as fast as possible, to perform all actions with as little risk for safety violations as possible, or whether to be courteous with customers to the point of striking

up conversation. Therefore, it was assumed that the test subject would balance the goals of quality, productivity, safety, and cordiality evenly and as came natural.

Multiple cycles of this activity were observed, and six cycles of this activity were video recorded for further motion analysis.[1]

RESULTS

First, it is important to view the data recorded from the motion analysis. The first table (Table 2) below lists all of the specific elements performed by each hand. This table expounds upon the actual Therbligs themselves, providing a detailed description of the motions. The second table below (Table 3) is a more succinct listing of Table 1, with just the Therbligs listed for each hand, as well as the change in time for each motion rather than the running time on the y-axis.

Table 2: Detailed Simultaneous Motion Table (L and R Hand Motions vs Running Time)

Time (seconds)	Left hand work element	Right hand work element
0.00	Idle (taking order)	Idle (taking order)
1.53		Reach for bagel
3.60		Grasp bagel
3.86	Reach for bagel	Move bagel (toward L hand)
5.27	Grasp bagel	Release bagel
5.40	Move bagel	Reach for knife
5.79	Position bagel on table	Grasp knife
5.86	Hold bagel	Move knife to bagel
6.56		Position and Use knife (4 oscillations)
8.86	Move bagel to different position	Move knife
9.10	Rotate bagel	Grab and rotate bagel (still holding knife)
9.73	Position bagel	Move knife
10.43	Hold bagel (2 oscillations)	Cut bagel (2 oscillations)
12.69	Move bagel	Move knife
13.17	Move bagel	Release knife
13.20	Move bagel	Move hand toward bagel
13.30	Release bagel	
13.33	Disassemble bagel	Disassemble bagel
14.26	Release bagel halves	Release bagel halves
14.30	Move hand toward container	Move hand toward knife
15.00		Grasp knife
15.23	Grasp container of cream cheese	Move knife toward container

[1] One cycle was recorded close-up and six cycles were recorded at a greater distance. However, for the six-cycle analysis, the close-up cycle is used for cycle 1-of-6 because the video tape for the actual 1-of-6 cycle was started midway through the cut.

15.26	Position container	
15.53	Grasp container	Use knife (load cream cheese)
17.26	Release container	Move knife to bagel (left half)
17.63	Grasp bagel (left half)	Use knife (spread cream cheese on left half)
18.33	Move bagel (left half), rotating slowly	Lift knife
18.53		Use knife (spread cream cheese on left half)
19.07		Lift knife
19.50		Use knife (spread cream cheese on left half)
19.89		Lift knife
20.13		Use knife (spread cream cheese on left half)
20.83		Lift knife
21.33		Use knife (spread cream cheese on left half)
22.43		Lift knife
22.73		Use knife (spread cream cheese on left half)
22.86		Move knife to container
22.89	Move hand toward container	
23.43	Grasp container	Use knife (load cream cheese; 2 osc)
24.69	Hold container	Move loaded knife toward bagel (left half)
24.83	Move hand toward bagel (left half)	
25.23	Grasp bagel (left half)	Use knife (spread cream cheese on left half)
25.76	Move bagel (left half), rotating slowly	Move knife
26.20	Move bagel (left half), rotating slowly and lifting	Use knife (spread cream cheese on left half)
27.03	Move bagel (left half), rotating slowly	Move knife
27.92	Move bagel (left half), rotating slowly	Use knife (spread cream cheese on left half)
28.43	Move bagel (left half)	Move knife
29.26	Hold bagel (left half)	Release knife on to top of container on left
29.30		Move hand to bagel (right half)
29.69		Grasp bagel (right half)
29.73	Hold bagel (left half)	Lift bagel (right half)
30.46		Assemble modified bagel
31.13	Grasp middle/top of modified bagel	Grasp underneath modified bagel
31.46	Move modified bagel to center of paper	Move modified bagel to center of paper
31.76	Release modified bagel	Release modified bagel
31.79	Move hand to left edge of paper	Move hand to right edge of paper
32.03	Grasp left edge of paper	
32.07	Assemble paper covering	
32.36		Grasp paper
32.43		Assemble paper covering
32.86	Move fully assembled bagel	Move fully assembled bagel
33.79	Release fully assembled bagel to customer	Release fully assembled bagel to customer

Table 3: Simultaneous Motion Table (L and R Hand Therbligs vs Running time & Change in Time)

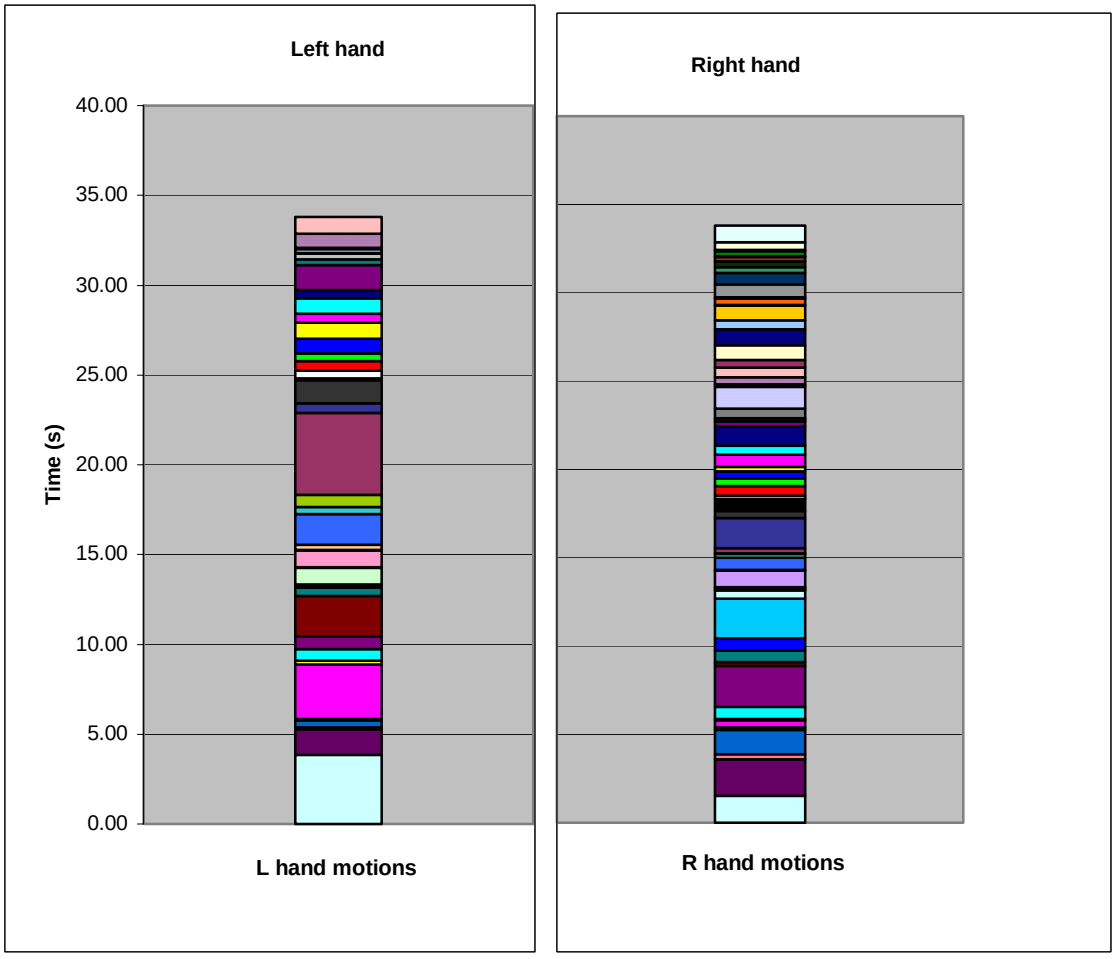
Time (seconds)	Left hand work element	Left Change in time	Right hand work element	Right Change in time

0.00Idle		Idle	
1.53		Reach	1.53
3.60		Grasp	2.07
3.86Reach	3.86	Move	0.26
5.27Grasp	1.41	Release	1.41
5.40Move	0.13	Reach	0.13
5.79Position	0.39	Grasp	0.39
5.86Hold	0.07	Move	0.07
6.56		Use	0.70
8.86Move	3.00	Move	2.30
9.10Move	0.24	Grasp	0.24
9.73Position	0.63	Move	0.63
10.43Hold	0.70	Use	0.70
12.69Move	2.26	Move	2.26
13.17Move	0.48	Release	0.48
13.20Move	0.03	Move	0.03
13.30Release	0.10		0.10
13.33Disassemble	0.03	Disassemble	0.03
14.26Release	0.93	Release	0.93
14.30Move	0.04	Move	0.04
15.00		Grasp	0.70
15.23Grasp	0.93	Move	0.23
15.26Position	0.03		0.03
15.53Grasp	0.27	Use	0.27
17.26Release	1.73	Move	1.73
17.63Grasp	0.37	Use	0.37
18.33Move	0.70	Move	0.70
18.53		Use	0.20
19.07		Move	0.54
19.50		Use	0.43
19.89		Move	0.39
20.13		Use	0.24
20.83		Move	0.70
21.33		Use	0.50
22.43		Move	1.10
22.73		Use	0.30
22.86		Move	0.13
22.89move	4.56		0.03
23.43Grasp	0.54	Use	0.54
24.69Hold	1.26	Move	1.26
24.83Move	0.14		0.14
25.23Grasp	0.40	Use	0.40
25.76Move	0.53	Move	0.53
26.20Move	0.44	Use	0.44
27.03Move	0.83	Move	0.83
27.92Move	0.89	Use	0.89
28.43Move	0.51	Move	0.51
29.26Hold	0.83	Release	0.83
29.30		Move	0.04
29.69		Grasp	0.39
29.73grasp	0.47	Move	0.04

30.46		Assemble	0.73
31.13Grasp	1.40	Grasp	0.67
31.46Move	0.33	Move	0.33
31.76Release	0.30	Release	0.30
31.79Move	0.03	Move	0.03
32.03Grasp	0.24		0.24
32.07Assemble	0.04		0.04
32.36		Grasp	0.29
32.43		Assemble	0.07
32.86Move	0.79	Move	0.43
33.79Release	0.93	Release	0.93

Figure 3 represents a simultaneous motion chart for each hands' motions. Each different shaded segment of the bar graph coincides with the motions listed on the tables above (tables 2 and 3), and the larger segments represent motions that took a longer period of time.

Figure 3: Simultaneous Motion Chart



After looking at the detailed data within each cycle, it is important to analyze the time segments for the major portions of the job task from all six cycles to determine data on

time averages and variance. The following table lists time data for each of the major tasks for each of the cycles, as well as cumulative times for each cycle.

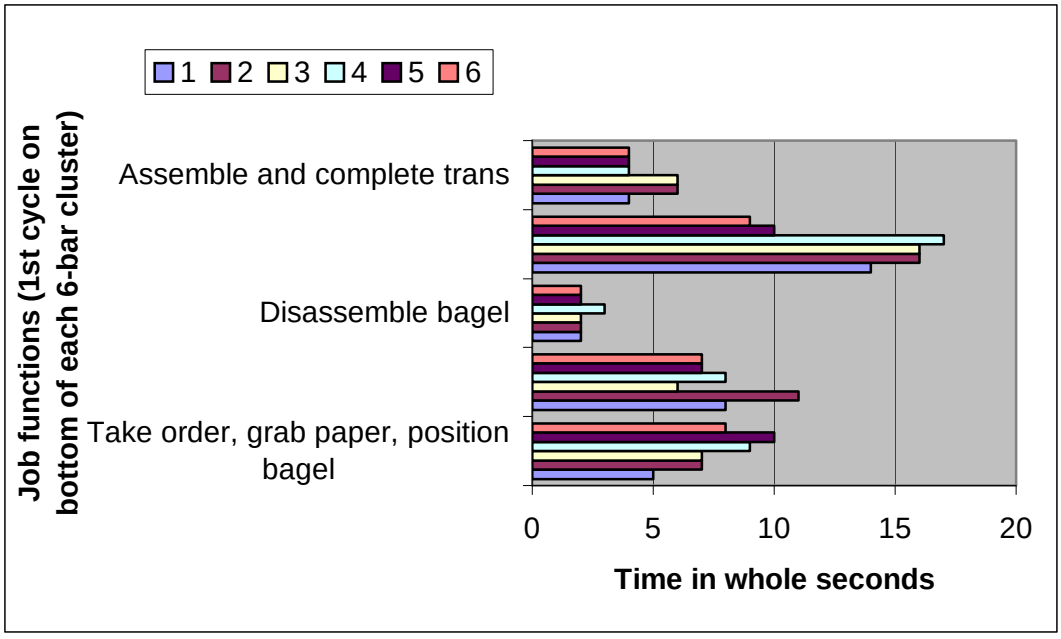
Table 4: Time breakdown (in seconds) for major job tasks (6 cycles listed in left column)

	Take order, grab paper, position bagel	Cut bagel	Disassemble bagel	load and spread cheese	Assemble and complete trans	Total time
1	5	8	2	14	4	33
2	7	11	2	16	6	42
3	7	6	2	16	6	37
4	9	8	3	17	4	41
5	10	7	2	10	4	33
6	8	7	2	9	4	30

Based on these six cycles, the mean length of each cycle was 36.0 seconds and the standard deviation was 4.82 seconds, indicating that there was notable variation. Further, although the final two cycles showed some evidence of a learning curve, the remaining data reflected a somewhat random distribution of the results. It appears that the largest sources of variation were in the very first step, in which the test subject took the order, grabbed the paper, and positioned the bagel, and there were secondary sources of variation observed in the cutting and cheese-spreading steps.

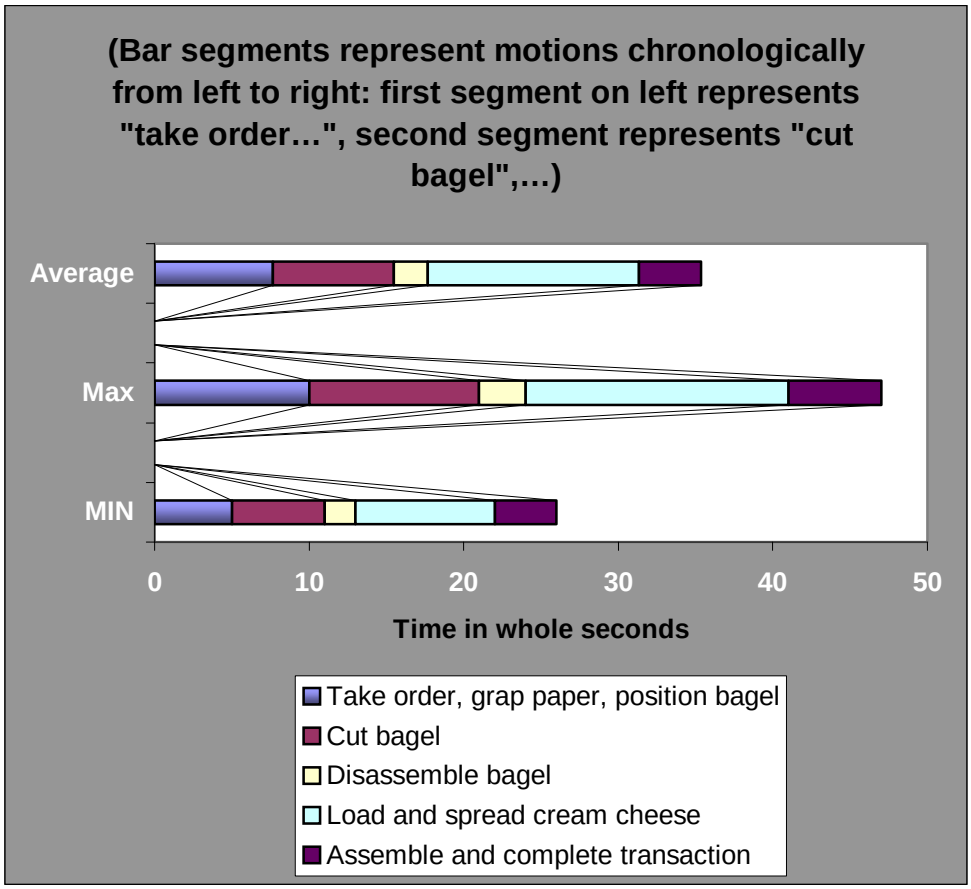
On the following chart, the time that was spent on major tasks for the six cycles are listed in terms of time spent.

Figure 4: Time Spent on Major Job Tasks (6 cycles)



The following figure (Figure 5) analyzes this data in terms of maximums, minimums, and averages.

Figure 5: Motion chart for bagel operation based on max, min, and average times for 6 cycles



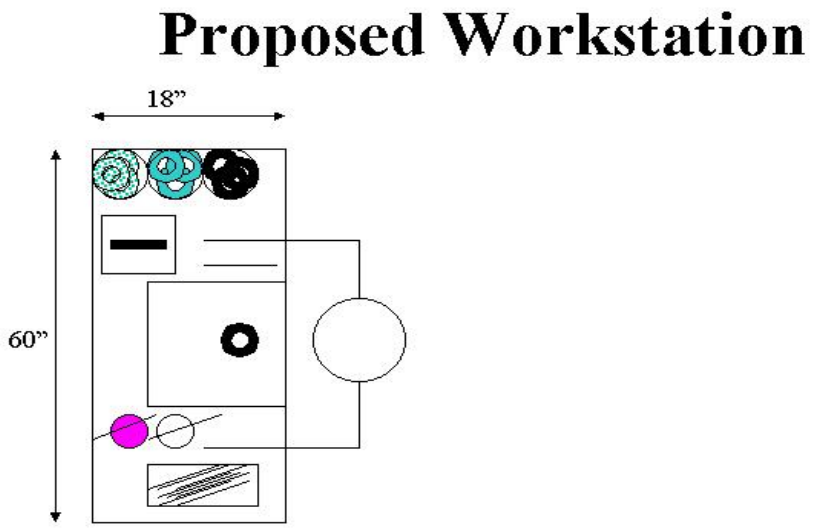
CONCLUSIONS

In order to propose a more efficient layout and operations procedure, it is important to isolate wasted motions. According to Nieble and Freivalds (2003, as cited in Armstrong, 3-2, "Methods Analysis and Ergonomic Work Enhancements"), non-value added elements for this operation included "position," "hold," and "select" (although "select" was not listed specifically in Tables 2 and 3, it essentially describes a part of what happening during "idle" step.)

Because the "position" step took place in order to increase the safety factor during the cutting process, this step should not be compromised in any way. In a similar fashion, the "hold" steps listed in the table were integral in presenting the bagel, and this fact combined with the fact that their sum only amounted to approximately 1-2 seconds, indicates that these are not where the revision efforts should be focused.

Where there was considerable potential for time saving was in the initial steps of selecting the bagel, the process of spreading the cream cheese, and the process of cutting the bagel. The greatest variance in the major steps analyzed in Table 4 and Figures 4 and 5 were noted in the first step of selecting the bagel, and was most likely due to the timing of the customer's request. Nonetheless, there was room for improvement for this step. If the bagels were taken out of their bags before the entire operation began and placed in containers that would fit on top of the Table 2, it would eliminate the need for a Table 1 and should reduce the time in this first step (prior to cutting the bagel) by approximately 2 seconds. In addition to the time saved by the physical turning around and selecting, the process should be easier on the employee, saving him / her kinetic energy and reducing head motion, thereby increasing mental focus.

Figure 6: Proposed Workstation



By far, the longest time was spent loading the knife with cream cheese and spreading it on the bagel. It was noted that of the six cycles, three times there were two trips made to the cream cheese bin to load the knife. However, this extra trip did not necessarily increase the time spent, as one of the one-trip cycles still had a total loading / spreading time of 16 seconds, which was the second most amount of time recorded for this step. It can be argued that the subject spent abnormally more time loading the knife before the one-trip cycle than the two-trip cycles, and also that he may have spent more time spreading due to having less product with which to work. Nonetheless, it is suggested that steps be removed from this process to save time. It will still take 2.03 seconds to load the cheese, but rather than spend the average of 13.7 seconds to spread the cheese on the bagel, it is recommended that the cheese be spread on the bagel with one motion, which occurred in 0.6 seconds. This should allow for an average savings of 13.1 seconds

for this step. Obviously, this will result in not much of a spread at all, and in order to maintain a high degree of quality and customer satisfaction, it is recommended that a plastic knife be served with the bagel in order that the customer can spread the cheese him / herself. It is estimated that it will take the employee an additional 1 second to obtain this item and give to the customer at the end of the transaction; thus net savings on this revision should be 12.1 seconds. It should be noted that such a significant time savings should offset the variable cost of the plastic knives.

The second longest major job task was cutting the bagel (7.83 seconds on average.) A simple way to reduce this time would be to use a sharper knife, which would eliminate the second run that the subject performed on every cycle to complete the cut. Thus, using the observed cycle as a model once again, the subject will still spend 2.30 seconds for his cut. This is a conservative estimate due to the fact that it takes into account 4 observed oscillations still within that first cut, some of which may be eliminated with the use of a sharper knife. The cut should be complete after this cut, saving a total of 4.31 seconds on this run. It should be noted that eliminating this step would also eliminate a fairly major safety hazard observed during the operation. In between the two cuts, the test subject used his hand holding the knife (right hand), while still holding the knife, to rotate the bagel. In the event that the proposed change does not go into effect, it is suggested that two steps be added in which he puts the knife down to rotate the bagel and then picks the knife back up when finished with the rotation. However, this change would not be necessary under the new operational format.

In sum, with the new layout and operations changes, a total of (2.0 + 12.1 + 4.3) = 18.4 seconds should be saved, thereby reducing the average total time in half from 36 seconds to 17.6 seconds. This change translates into a production change from less than 2 bagels per minute to nearly 3.5 bagels per minute. It also reduces safety hazards, makes the workplace layout more comfortable for the employee, and should maintain a high level of quality.