WORK MEASUREMENT FOR ESTIMATING FOOD PREPARATION TIME OF A BIOREGENERATIVE DIET

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ABSTRACT

During space missions, such as the prospective Mars mission, crew labor time is a strictly limited resource. The diet for such a mission (based on crops grown in a bioregenerative life support system) will require astronauts to prepare their meals essentially from raw ingredients. Time spent on food processing and preparation is time lost for other purposes. Recipe design and diet planning for a space mission should therefore incorporate the time required to prepare the recipes as a critical factor. In this study, videotape analysis of an experienced chef was used to develop a database of recipe preparation time. The measurements were highly consistent among different measurement teams. Data analysis revealed a wide variation between the active times of different recipes, underscoring the need for optimization of diet planning. Potential uses of the database developed in this study are discussed and illustrated in this work.

KEYWORDS: diet, food preparation, space, time studies, work measurement

CONTENT SENTENCE: Work measurement videotaping techniques are used to collect labor time data on food preparation activities of a bioregenerative life-support space diet.

INTRODUCTION

During space missions, such as the prospective Mars mission, the availability of crew labor time is a strictly limited resource (11). Any tool used to increase task efficiency or to make the schedule of astronauts more manageable will benefit both astronauts and mission planners. On current Shuttle missions, the crew time devoted to preparation and cleanup of prepackaged food ranges from 45 to 90 minutes/day total (9). In a bioregenerative life support system (BLSS), astronauts will have to prepare their meals using the crops grown in a hydroponic system. Such meal preparation from basic ingredients will consume far more of the crew's time than currently experienced. Accurate estimates of the crew time required for food preparation are needed to support NASA's decisions on food system choices for long duration missions. The economic component of those decisions is likely to use equivalent system mass (ESM) analysis.

Equivalent system mass (ESM) is a measure that converts physical units of non-mass resources such as power, pressurized volume and crew labor into equivalent payload mass by multiplying the units with appropriate mass penalties. ESM accounting of plans for space missions allows for the comparison among different life support system options using a single unit of measure: the ESM of the option (6, 10). The ESM cost of labor [kg/work hour] will depend on the ESM of the life support system, the number of hours in a standard workweek and other life support demands on crew time.

The first step in the development of models for predicting work-times during a space mission is timing of the tasks on the ground. For example, in the development of crew schedules for Space Shuttle experiments, ground simulations were used to predict the labor requirement of each step in an experiment (Johnson, C. personal communication). Videotape analysis techniques are well suited to this task and have been used by NASA to document space usage by the crew during the LMLSTP III closed chamber test (21).

This paper presents a method for estimating food preparation time using videotape analysis and reviews the results of applying this method to the time study of a small group of recipes suitable for a bioregenerative diet.

We suggest that NASA apply work measurement techniques to ground simulations of food preparation and other life support activities as a prelude to planning tasks during future space and planetary missions. Together with ergonomics, this information can help in designing the food preparation area for future missions. We considered food preparation for only planetary surface missions since food processing and preparation is very difficult in microgravity.

Model for Current Study

This project described in this paper was part of a larger study aimed at optimizing the crew diet for a bioregenerative planetary surface mission (12). Food preparation labor must be estimated in order to include it as a cost in the system. For this labor study, each recipe is analyzed into its component tasks. Food processing labor and food preparation labor are calculated and separately assigned to the processing costs of ingredients and the preparation cost of recipes, respectively. The ESM cost estimation procedures used are outlined in (6, 10).

History of Work Measurement Techniques

Measurement and analysis of work has been used since the industrial revolution to improve worker productivity and comfort. Robert Owen, the first to analyze work as a process, identified the need for rest and fatigue allowances for workers, and showed that output was not directly proportional to time worked (26).

Contemporary work measurement was founded at the turn of the century by Frederick Taylor. He created a technique for standardizing performance times of repetitive operations by specifying the method of operation and by timing the component tasks with a stopwatch (13).

In the 1920's, sampling theory made possible more effective data collection and the use of larger sample sizes. In the 1930's, Frank and Lillian Gilbreth established motion study, used to simplify and speed up assembly line tasks. The Gilbreths developed micromotion cinematography to take precise and consistent measurements of tasks. They subdivided repetitive tasks into micromotions, such as ‘reach’, ‘grasp’, and ‘position’, allowing for detailed analysis of manual work. Their data, among others, were used to create “predetermined motion-time system” models which predict the time requirement for a given task from the times required for its micromotions. Work analysis remains a key tool of manufacturing engineering (17) and has been applied to issues of cost management as well as assembly line operation (26).

Types of Work Measurement Techniques

Four major techniques are used for work measurement: Time Study, Standard Data, Predetermined Time Systems, and Work Sampling (2). Usually the objective of work measurement is the development of a *standard time*, defined as the time required by an average worker, working at a normal pace, to complete a specified task using a prescribed method. The tasks of interest here are the preparation of various recipes by a cook with average kitchen skills, who is familiar with the recipe and with the kitchen and pantry layout.

In Time Studies, data on task duration is collected using either a stopwatch or a video camera. The recording speed of the camera can be adjusted depending on the amount of detail needed. The task under study must have a well-defined beginning and end. It should be measured only under typical situations, and for privacy and wage negotiation reasons, all the parties involved in the study should be informed in advance (22). The task should have a relatively short duration but have sufficient duration to be accurately timed.

Predetermined Time Systems (PTS) methods rely on a systematic procedure which subdivides any complex manual task into motions, body movements, or other elements of human performance, and assigns to each element the appropriate time value from a table of time/motion data.

The third main method of work measurement is Standard Data. The inputs for a "standard data" analysis come from time studies and/or predetermined time system estimates (22). Standard data systems organize standard times from a number of related tasks into a database from which the standard times for related jobs may be predicted (1); in essence, it is a means to adjust or extrapolate PTS or time studies results to new tasks.

Work Sampling is a statistical method where an analyst records, at random intervals, the type of task the worker is doing. The number of observations recording a particular task reveals the fraction of worker time devoted to that task. Statistical formulas are used to determine the correct number of work samples to record based on rough estimates of the duration and frequency of each task (1). This method is usually applied to investigate the division of worker time among the various activities that comprise a job or a work situation (22), and is best suited to jobs of long duration and low repetition.

The choice of a work measurement technique depends on several factors: the nature of the job being analyzed (its complexity and use of repetitive tasks), the number of people involved, time and budget constraints, and the objectives of the study (7).

Work Measurement in Food Production

In the food industry, work measurement is applied to improve productivity in industrial processing or in food service level contexts such as hospitals or chain restaurants (8,18). For example, Time and motion studies were used by Burger King management to cut transaction time to 30 seconds at the drive-through service window (15).

Hospital dietary units have used work measurement to identify opportunities for productivity improvement. Donaldson (5) used work sampling to measure the productivity of food production personnel and the labor time per meal. Blanken (3) first measured tasks, then improved productivity by reallocating the tasks among personnel according to relevant time or employee constraints.

Motion and time studies, as well as sampling techniques, have been successfully employed to isolate costly functions and to improve the efficiency of kitchen workers (19, 27, 4, 24). Work sampling has also been used to measure supervisory and managerial work in a kitchen setting (20, 23). A study by Montag (16) aimed at assessing the use of predetermined motion time systems in order to predict the production times for specific foods. The author concluded that while consistent estimates could be made, the time needed to conduct the analysis was too long and beyond economical benefit.

MATERIALS AND METHODS

From the available methods of work analysis, the time study method was chosen because the work performed included the preparation of many different recipes with very little repetition. Although a predetermined time system would have worked, it would have required too fine a level of detail and would not have been cost effective. Work sampling is often applied to activities with relatively long cycle and a low degree of repetition such as some of our cooking tasks, but it requires a large number of observations, impractical in our case since each recipe was filmed only once. Although each recipe was filmed only once, the individual tasks were replicated many times across the different recipes.

Data Collection

Video data were collected using two camcorders (Sony Video 8XR model CCDTRV15) positioned near the ceiling on opposite sides of the food preparation room and focused on the five major workstations: central island, sink, stove, food processor and oven. Camera positioning allowed for an overlapping view of the food preparation area. The camcorders were equipped with time stamps and dates, and were synchronized to the nearest second. The microphones on the two camcorders had good sound quality, necessary for the chef who was required to verbally identify any steps, tasks or ingredients that might be difficult to identify in the video analysis. The camcorders fed individually into two VCRs (Panasonic model 8405S) which were linked to a Zenith monitor (model #A13PO2D) which allowed the chef to check for proper camera function before starting work. Resulting tapes were replayed using a VCR with a jog dial (Sony model SLV-77Hi-Fi) which enabled the viewer-analyst to advance the action frame-by-frame to accurately record task start and end times. The preparation sessions for a total of 40 recipes were videotaped in this manner.

In all of the videotaped recipes, the person videotaped was the chef (a research support specialist) on the project. The chef had long experience in food preparation and was preparing each of the recipes for the second time when the videotaping occurred. This corresponds somewhat to the astronaut situation because the astronauts will be expected to have some culinary training and will become familiar with the recipes as they prepare them. On the other hand, we recognize that skill level can have a large impact on food preparation times. For example, a preliminary study (R. Spies and R. Relinger, 2000), not reported here, of three subjects (inexperienced, trained, and professional) revealed differences in task times as high as 1000% for difficult tasks such as slicing mushrooms. For consistency, our video data are based on a single skill level. The only criterion adopted for the selection of recipes for filming was to cover a wide range of different food categories such as breakfast foods, main dishes, soups, appetizers, etc.

Videotape Analysis

Video analysis in this project was a 3-step process. For each recipe, a group of task analysts initially created a list of expected tasks based on the recipe, and then edited this list during a first viewing of the videotape, adding additional tasks and noting videotape segments that would be classified as time-off tasks, failed actions, or mistakes (such as dropping a piece of food). The finished task lists were passed along to a second group of two viewers who recorded the time elapsed for each task to the nearest second, using the time stamp on the video, and entered the data into a database.

A key concern in developing the methodology was to ensure consistent classification and measurement of videotape events by a diverse collection of volunteer videotape analysts. Two types of inconsistencies were anticipated: first, that different analysts would classify similar activities in different ways, and second, that task durations would show significant between-analyst variation. To guard against these kinds of inconsistencies, as well as to distribute the workload, we separated the classification analysis from the measurement analysis. Each recipe was coded (analyzed into tasks) by exactly one task definition team and measured, during the preliminary analyses, by at least two task measurement teams. To guard against the first inconsistency, the task definition teams met frequently as a group to create a standard list of tasks and to resolve classification issues. To guard against the second inconsistency, the task definition team produced a set of tasks (Appendix A) and identification guidelines for the measurement teams.

Task List Development

The goals of task list development were to ensure coverage of all activities occurring in the 40 videotaped recipes, to avoid overlap between task definitions created, and to make the list short and simple. The tasks were defined to be easily understood by students on the task measurement teams. A list of 55 cooking tasks (including dead time) was first developed from the recipe sheets of 40-videotaped recipes (Appendix A). Representative tasks are shown in Table 1. The recipes used in the study typically had a batch size of 6 to 12 servings. Identification of the start and end times for each task were defined in terms of the tools used. Thus, the task began whenever the equipment or ingredient was grasped by the chef and ended when it was released. This approach greatly reduced the problem of ambiguity in analyzing task durations and contributed to the consistency found among measurements by different analysts. Since the duration of transits between workstations varies with the size and design of the kitchen, the time spent on transits was not included in the total time of the particular task, but was called out separately as a transit.

Four general task categories were defined. The first and most important was that of *active tasks* such as peeling, washing, measuring, cutting, assembly, and various types of cooking tasks. The second category consisted of *passive tasks* which did not require continuous involvement. Examples included tasks such as boil, cook, bake, and preheat. Active tasks could be performed during execution of a passive task. The third category was *transits*, that is, movement between workstations.

INSERT TABLE 1 AROUND HERE

The fourth category was *dead time*, accounting for interruptions such as phone calls or tasks for another recipe. Two additional tasks, the weighing of ingredients and the recording of measurements (writing) in the lab notebook, were recorded but not used in analysis because they would not be part of ordinary food preparation. Typically in food preparation, most of the ingredients are measured rather than weighed but weighing was done in this study for the sake of accuracy and other nutritional analyses that were required.

Database

A database was created in Microsoft Access 97 to hold the timing data for the different recipes. The database was designed to be user friendly, easily searchable by data queries, and expandable, with options of adding new dishes, new task actions and new task objects as necessary. Scrolling lists in the different tables were designed to minimize typing during data entry. The database structure, including variables used, the tables capturing these variables, and the relationships among the tables, is diagrammed in Figure 1. Note that each table has one or more links with the main table (Table Task and Times), into which the data were entered. The main variables for each task were Task Action, Task Object, Start Time, End Time, and comments (Table 2). Comments were added where necessary by the task definition team to facilitate data input, or by the data timing group in case of confusion or error.

INSERT FIGURE 1 AROUND HERE

INSERT TABLE 2 AROUND HERE

RESULTS AND DISCUSSION

We initially evaluated the methods and data of this study based on six food preparation events, each for a different recipe. These were taped and analyzed by the methods described earlier. Total recipe preparation time was divided among active food preparation time, passive time, dead time, transit time, weighing ingredients, and writing. Figure 2 displays the breakdown for each recipe. We focused on the active and passive food preparation time components because the other components offer little prediction value.

The first conclusion of the preliminary analysis was that between-analyst (different timing groups) task time variability was not significant ($p > 0.05$) as obtained from a two-way ANOVA. The two-way test was performed on five of the six recipes. (Asian Pesto was not included because it was measured by only one team.) The two factors considered in the ANOVA were the task number ("Task") and the team number ("Group"). While task factor was significant in all five recipes (p-value < 0.05), the group factor was not significant (p-value > .14). In particular, it was not significant for the one recipe measured by all four teams (Melon Ginger: p-value > 0.89).

INSERT FIGURE 2 AROUND HERE

Since the group factor was not significant, videotape analysis was continued on 10 additional recipes without replicating task time measurements. Figure 3 shows the breakdown of the 10 additional recipes into their time category components.

Preliminary analysis showed that the discarded time components (transits, weighing and writing) averaged 17.6% of the total recipe preparation time (Soy Wheat Crepes excluded). As expected, a large variation in active food preparation time was observed among the different recipes. Seitan Stir Fry, for example, has four times the active preparation time of Peanut Wheat Hot Cereal. These differences are likely to influence menu selection because of the high cost of labor.

INSERT FIGURE 3 AROUND HERE

Separate accounting of active and passive time allowed observation of differences between recipes that would have been obscured by grouping active and passive tasks together. For example, had the passive and active time been counted together in one time category then recipes like Potato Onion Bread and Tofu Cottage Cheese would have significantly different labor requirements. However, the active time is almost identical (37.37 and 40.48 minutes for Potato Onion Bread and Tofu Cottage Cheese, respectively). The length of passive time intervals and their sequence among active tasks is useful information when planning simultaneous preparation of several recipes, and may also provide information about adequate recipe combinations.

Tasks were also divided into two scaling categories: quantity dependent (QD) and quantity independent tasks (QI). QI tasks, such as picking up and putting down utensils, setting up equipment such as the food processor, or opening and closing containers do not vary in duration according to the batch size of the recipe. On the other hand, the duration of a QD task depends on the amount of material or ingredient used in the task and, hence, on the batch size. Examples of QD tasks are hand-chopping vegetables or fruits, rolling out dough, or peeling. The average durations across all recipes for tasks in the quantity independent and quantity dependent categories are shown in Figures 4 and 5 respectively.

INSERT FIGURE 4 AROUND HERE

INSERT FIGURE 5 AROUND HERE

On average, the QI tasks are much shorter in duration than the QD tasks. Fourteen of 20 QI tasks average around or under 10 seconds. As for the QD tasks, 29 of 34 are under 100 seconds.

Figure 6 shows a cumulative distribution function graph for three common quantity independent tasks: drain, check and close. The range of task times observed for these tasks is shown on the vertical axis. The distribution function captures the variation in task times observed. For example, approximately 75% of the tasks last longer than 30 seconds and are concentrated in a range between 30 and 35 seconds. The remaining 25% of the observations are distributed evenly over the broad range from 1 to 30 sec.

INSERT FIGURE 6 AROUND HERE

The ESM cost prediction; the required time per recipe can be estimated by summing the mean times for all active tasks. For QI tasks, this will simply be the average observed duration. For QD tasks, it will be an average task rate multiplied by the quantity of material to be processed. The total active time should be adjusted for transits, inflated by an appropriate dead time factor and added to the cleanup time (computed separately) to yield a total time requirement.

The value of the timing data collected extends beyond its use in measuring labor costs. Pareto analysis (25) of the task times for a recipe can lead to improved work methods to economize on labor. Figure 7 displays a Pareto analysis for the Seitan Stir Fry dish.

INSERT FIGURE 7 AROUND HERE

Table 3 lists the top ten tasks from this dish, in order of duration. The longest task turns out to be cutting pepper, a manual activity. This was due to the fact that the pepper had to be cut by hand into a combination of uniform thin slices and dice chunks. This task could be performed more quickly in a food processor or it could be shortened by specifying all slices, or all large chunks, as the shape of the food pieces. Thus, if a recipe is initially rejected from the menu optimization as too labor-intensive, modifications in the recipe or in work methods may permit it to be reconsidered.

INSERT TABLE 3 AROUND HERE

Another potential use of work measurement data is to optimize meal preparation activities, in situations in which several recipes are prepared simultaneously at a limited number of workstations, with the goal of having the entire meal ready at the same time. Such an optimization needs the following inputs: the time required by the various tasks in the recipes of interest, the required sequence of these tasks, and the resources needed for these tasks. Estimates for all of these parameters are easily derived from the video analysis. Figure 8 shows an example of a Gantt chart (14) to optimize the food preparation activities for a meal of 5 recipes. The recipes were among the most complicated of the recipe set and were chosen to show the use of multiple equipment stations and the challenges of sequencing active tasks with passive intervals such as baking and chilling. Gantt charts, named after Henry Gantt, are visual displays of task durations and sequences and can be used to analyze causes of delays. The arcs in Figure 8 indicate the task sequences. The workstations in the graph include the stove, oven, refrigerator, sink, freezer, food processor, blender, and counter. The active time used in the preparation of these 5 recipes was 3.5 hours. This unrealistic figure is due to the use of conservative task labor time estimates. Time study data were not available for the complicated recipes chosen.

INSERT FIGURE 8 AROUND HERE

As Figure 9 shows, most of the time needed for the production of the 5 recipes involved the use of the counter (center island), followed in order of usage by the stove and then the food processor.

INSERT FIGURE 9 AROUND HERE

The results of this type of analysis could lead to improvements in design of the food preparation area, automation of repetitive tasks or changing the capacity of equipment. For example, if work is frequently delayed because of limited counter space the counter space could be increased. Likewise, the manual tasks most in need of mechanization can be identified.

CONCLUSIONS

Estimating food preparation labor time is an important factor in optimizing menu selection for a bioregenerative diet. The food preparation tasks used in the recipes of this work should be, in their majority, adaptable to a planetary colony scenario. Recipe-specific labor requirements were measured by videotaping an experienced chef preparing the recipes, and then classifying and timing the distinct tasks required to prepare the recipe. This methodology produces consistent and accurate task duration estimates. Statistical analysis of the task durations found no significant effects due to data analyst group. As expected, preparation times varied considerably across recipes, underscoring the importance of including labor cost in a menu/diet optimization. Task analysis revealed opportunities to improve the labor cost of individual recipes. The cost of the food preparation labor is likely to have a significant impact on the menu and food system adopted for a Mars exploration mission. Obviously, certain additional factors would have to be accounted for, such as shifts in task durations due to the lower Mars gravity, or the substitution of flight- qualified kitchen equipment for the standard commercial equipment used in the project. The utility of the data acquired in this project will depend on adjustments for differences between transit times in the test kitchen and the Mars habitat galley. Still, ground simulation such as conducted in this study represents a logical first step in making labor time estimates for life support activities.

INSERT APPENDIX A AROUND HERE

ACKNOWLEDGEMENTS

Support of this work by the National Aeronautics and Space Administration under NASA Grant NAG 5-4222 and the GE Faculty of the Future program for undergraduate research is gratefully acknowledged.

BIOGRAPHICAL SKETCHES

Ammar Olabi is currently a post-doctoral fellow in the Food Science Department at Cornell University. He completed his B.S. in Nutrition and Dietetics and M.S. in Food Science at the American University of Beirut. In August 1995 he enrolled in the Food Science and Technology Ph.D. program at Cornell University. He conducted his Ph.D. research, focused on the optimization of a bioregenerative diet, under the supervision of Dr Jean Hunter.

Jean Hunter is an associate professor in Cornell's Department of Biological and Environmental Engineering. She holds a B. S. from MIT and M.S. and D. Eng. Sci. degrees from Columbia University, all in chemical engineering. Her research interests include food engineering, fermentation and enzyme technology, downstream processing, and the production of value-added products from food and agricultural residues. She has taught bioprocessing, bioseparations, a biological engineering laboratory course, and with Dr. Jackson, the undergraduate group research project on measurement of food preparation labor which developed the data for this paper.

Peter Jackson is an associate professor in the School of Operations Research and Industrial Engineering, Cornell University. He received a B.A. in Economics from the University of Western Ontario (1975), a M.Sc. in Statistics (1978) and a Ph.D. in Operations Research (1980) from Stanford University. He conducts research in production planning, resource scheduling, and inventory management and teaches courses in industrial systems analysis, design, and engineering. He is an innovator in experiential learning and the recipient of several teaching awards.

Michele Segal earned her B.S. at Florida State University in Psychology with a specialty in Environmental Psychology. She completed a M.S. in Human Factors at Cornell University, with a thesis on the use of active noise reduction headsets to improve speech intelligibility in the space shuttle mid-deck noise environment. She continued her work on noise and habitability after joining Johnson Engineering Corp., Houston, TX, in the International Space Station Acoustics group at NASA/ Johnson Space Center. Ms. Segal currently works in the Lighting Environment Test Facility at NASA/JSC and handles lighting and human performance issues aboard the space station.

Rupert Spies is a senior lecturer at the School of Hotel Administration, Cornell University, where he teaches courses in restaurant food production, restaurant management and catering. Besides his interest in food systems for NASA, he has also done research on multi unit restaurant management in Germany, and provided consulting in the areas of purchasing management, menu development and catering, and co-taught with Dr. Hunter and Dr. Jackson, the undergraduate group research project on measurement of food preparation labor. Prior to receiving his degree from the *Technische Universitae*t Berlin, he apprenticed and worked as a chef in various restaurants in Germany and abroad.

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TABLE 1. Examples of typical tasks

Task Action	Definition	Start of Task	End of Task
Add	To put an ingredient into a vessel. Does not include measuring.	Picking up utensil or contacting ingredient.	Releasing utensil or ingredient.
Bag	To put ingredients in a bag.	Getting the ingredient or picking up the bag, whichever occurs first.	Putting bag down.
Bake	To cook food item in the oven or in the bread machine.	Opening oven door to put item in / pressing start button on bread machine.	Closing door after removing item from oven or removing bread from bread machine.
Blend	To prepare a food item in the food processor. Includes chopping, pureeing, mixing, grinding, and kneading of dough in food processor. (includes checking to see if blending is done)	Securing food processor lid on central unit.	Pressing off button if the food item is not immediately removed.

TABLE 2. Typical task list

Soy Wheat Crepes Starts on November 12 at 3:40:00 PM					
Task	Object	Time started	Time Ended	Time Elapsed	Comments
Read	recipe	3:55:11	3:55:19	0:00:08	p.m.
Get	strawberries	3:55:19	3:55:20	0:00:01	
Transit		3:55:20	3:55:21	0:00:01	
Put	strawberries	3:55:21	3:55:22	0:00:01	
Chop	strawberries	3:55:22	3:59:30	0:04:08	
Transit		3:59:30	3:59:31	0:00:01	
Wash	bowl	3:59:31	3:59:32	0:00:01	Get bowl
Transit		3:59:32	3:59:34	0:00:02	
Wash	bowl	3:59:34	3:59:38	0:00:04	
Transit		3:59:38	3:59:40	0:00:02	
Wash	bowl	3:59:40	3:59:42	0:00:02	Put bowl

TABLE 3. Ten longest tasks for Seitan Stir Fry recipe (sum of all occurrences of the task within the recipe)

TASK	RANK	DURATION (seconds)
Dead time	1	360.5
Cut pepper	2	326.5
Transit	3	261.5
Stir	4	172.5
Cut onion	5	130.5
Stir vegetables	6	116.5
Core pepper	7	99.5
Chop seitan	8	89.5
Read recipe	9	83.5
Bag peppers	10	74.5

APPENDIX A

List Of Task Actions

Task Action	Task Action
Add	Make (Pasta, i.e. mix dough)
Bag	Measure
Bake	Open
Blend	Peel
Boil	Preheat
Check	Press
Chop	Put
Clean	Read
Cleanup (several cleaning tasks in sequence)	Rearrange
	Rise
Close	Roll
Cook	Set up
Core	Shake
Cover	Soak
Crush	Sort
Cube	Spread
Cut	Stir
Dead Time	Taste
Discard	Tear
Divide	Transit
Drain	Trim
Empty	Turn on
Fill	Turn off
Flip	Wash
Get	Weigh
Grease	Wipe
Knead	Write
Load	Miscellaneous Tasks

FIGURE 1. Database structure, showing tables, variables within tables and relationships among the tables.

FIGURE 2. Major components of recipe tasks: active time, passive time, dead time, transit, weighing and writing for 5 recipes: Ginger Melon, Seitan Stir Fry, Whole Wheat Pasta, Peanut Wheat Hot Cereal, Soy Wheat Crepes, Asian Pesto.

FIGURE 3. Major components of recipe tasks: active time, passive time, dead time, transit, weighing and writing for 10 recipes: 1= Potato Onion Bread, 2 = Dill Potatoes, 3 = Tofu Cottage Cheese, 4 = Scrambled Tofu, 5 = Cinnamon Peanut Rolls, 6 = Vegetable Pasta Salad, 7 = Jerk Tofu, 8 = Chocolate Sauce with Strawberries, 9 = Broiled Zucchini with Herbs, and 10 = Cold Beet Borscht.

FIGURE 4. Average durations (seconds) across all recipes for quantity independent tasks. 1 = Put, 2 = Discard, 3 = Turn Off, 4 = Get, 5 = Taste, 6 = Close, 7 = Rearrange, 8 = Open, 9 = Drain, 10 = Read, 11 = Clean, 12 = Check, 13 = Set Up, 14 = Write, 15 = Wipe, 16 = Turn On, 17 = Miscellaneous, 18 = Empty, 19 = Cleanup, 20 = Sort.

FIGURE 5. Average durations (seconds) across all recipes for quantity dependent tasks. 1 = Transit, 2 = Cook, 3 = Cover, 4 = Shake, 5 = Weigh, 6 = Bag, 7 = Fill, 8 = Grease, 9 = Rise, 10 = Add, 11 = Measure, 12 = Wash, 13 = Soak, 14 = Blend, 15 = Spread, 16 = Stir, 17 = Load, 18 = Knead, 19 = Cut, 20 = Tear, 21 = Roll, 22 = Flip, 23 = Core, 24 = Press, 25 = Crush, 26 = Peel, 27 = Chop, 28 = Divide, 29 = Cube, 30 = Preheat, 31 = Make, 32 = Boil, 33 = Trim, 34 = Bake.

FIGURE 6. Cumulative distribution function for 3 common quantity independent tasks: drain, check and close.

FIGURE 7. Pareto analysis of the task average durations (seconds) for Seitan Stir Fry. Each bar corresponds to a task-object combination.

FIGURE 8. GANTT chart for the production of 5 recipes. Kale Soup (dark gray), Potato Salad (light gray), Oven Roasted Vegetable Sandwich (black), Jerk Tofu (white), and Strawberry-Pineapple Drink (darkest gray). The arcs indicate the task sequences. The workstations are listed on the y-axis.

FIGURE 9. Time use (as a percentage) of the kitchen workstations (stove, oven, counter, sink, fridge, freezer, food processor, and blender) for the production of 5 Recipes: Kale Soup, Potato Salad, Oven Roasted Vegetable Sandwich, Jerk Tofu, and Strawberry-Pineapple Drink.

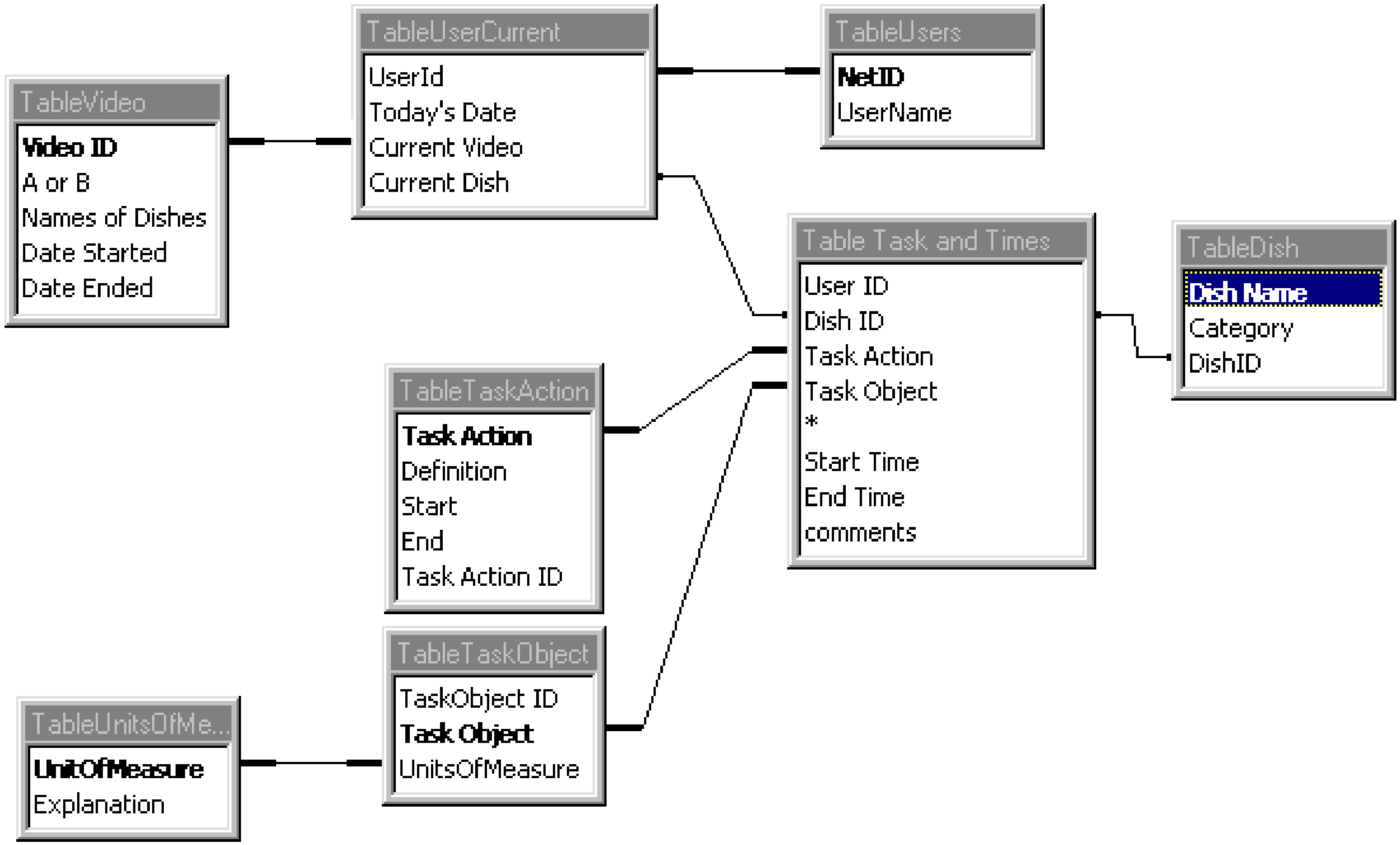
TableVideo
Video ID
A or B
Names of Dishes
Date Started
Date Ended
TableUserCurrent
UserId
Today's Date
Current Video
Current Dish
TableUsers
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Table Task and Times
User ID
Dish ID
Task Action
Task Object
*
Start Time
End Time
comments
TableDish
Dish Name
Category
DishID
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Start
End
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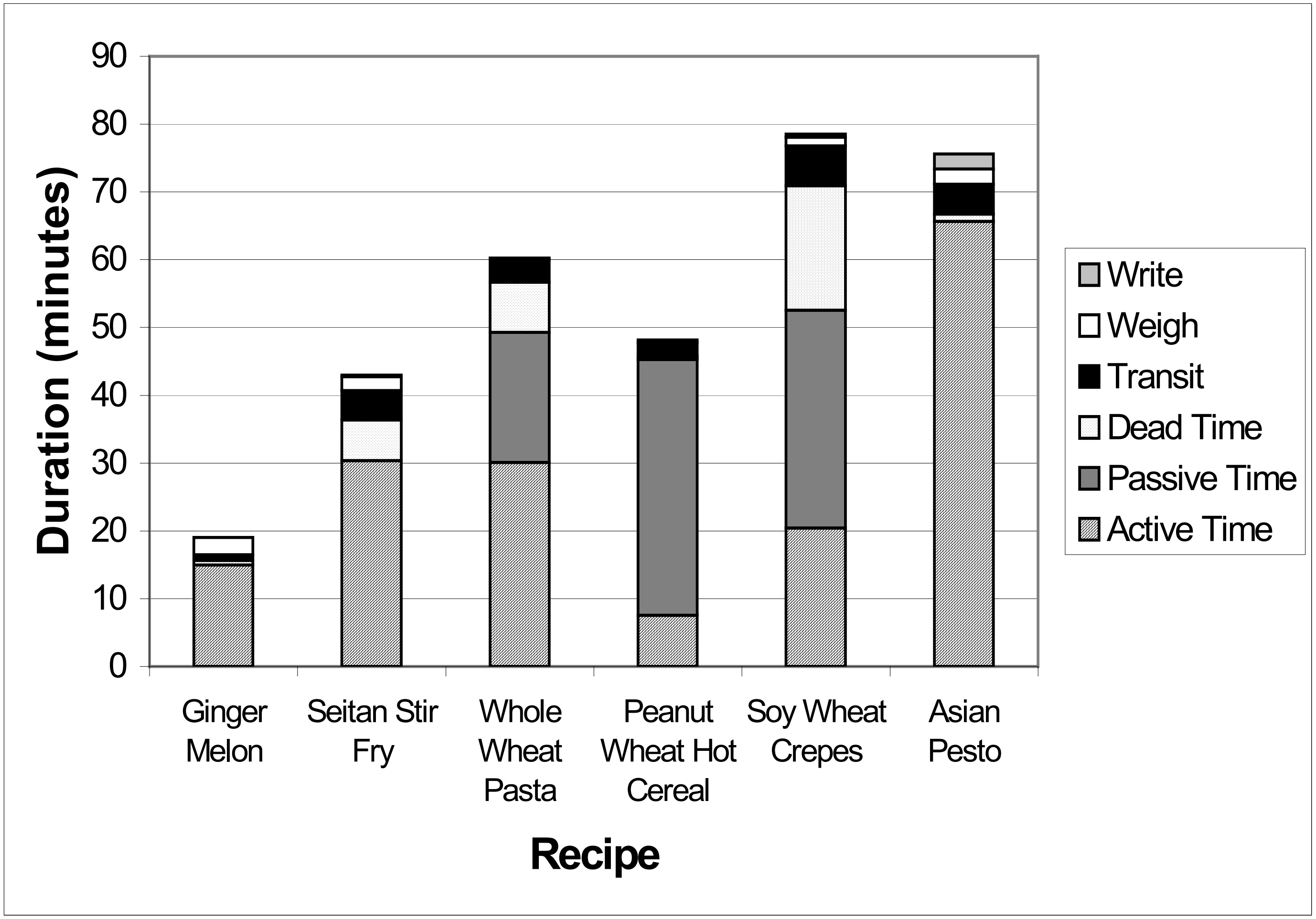
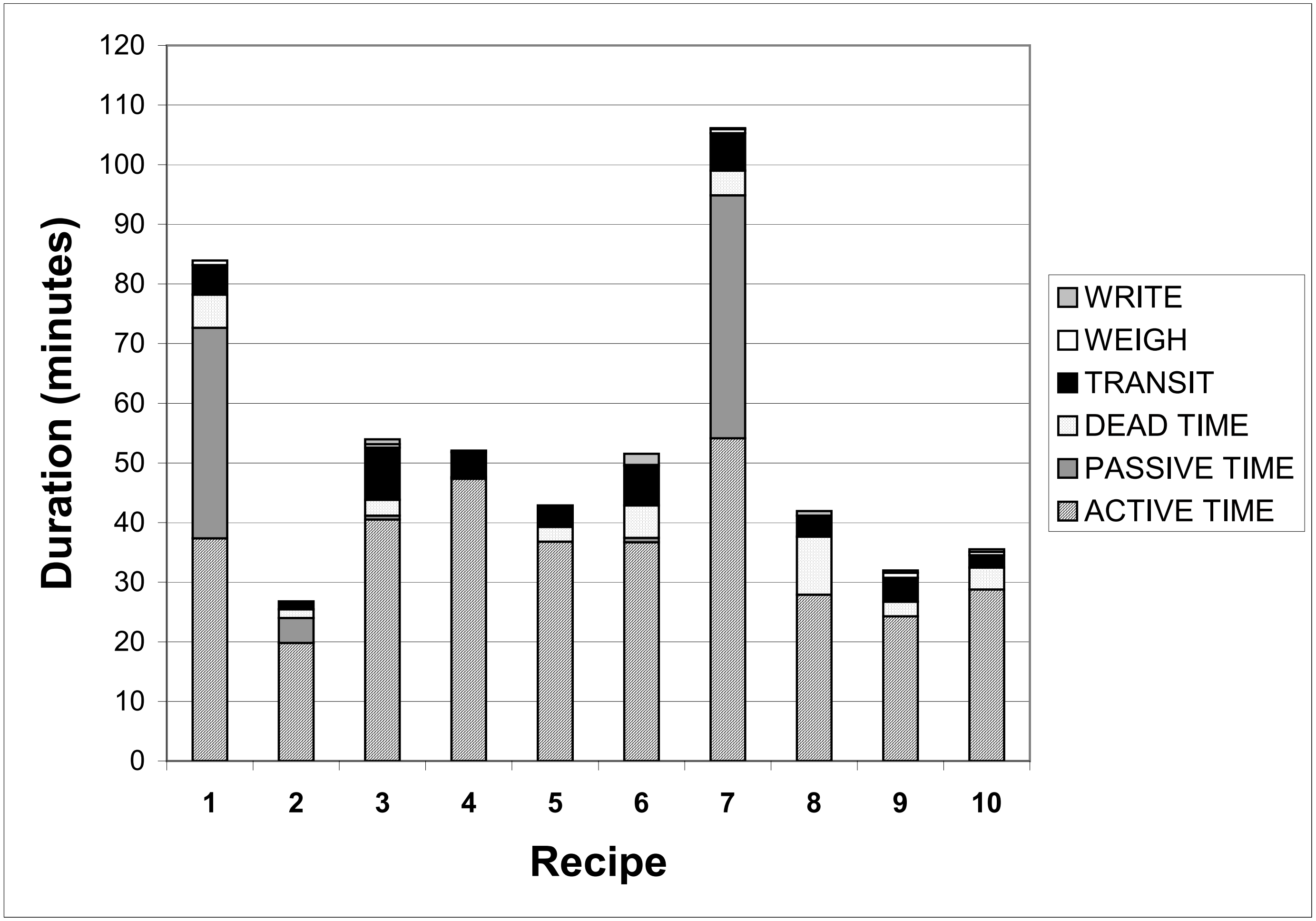
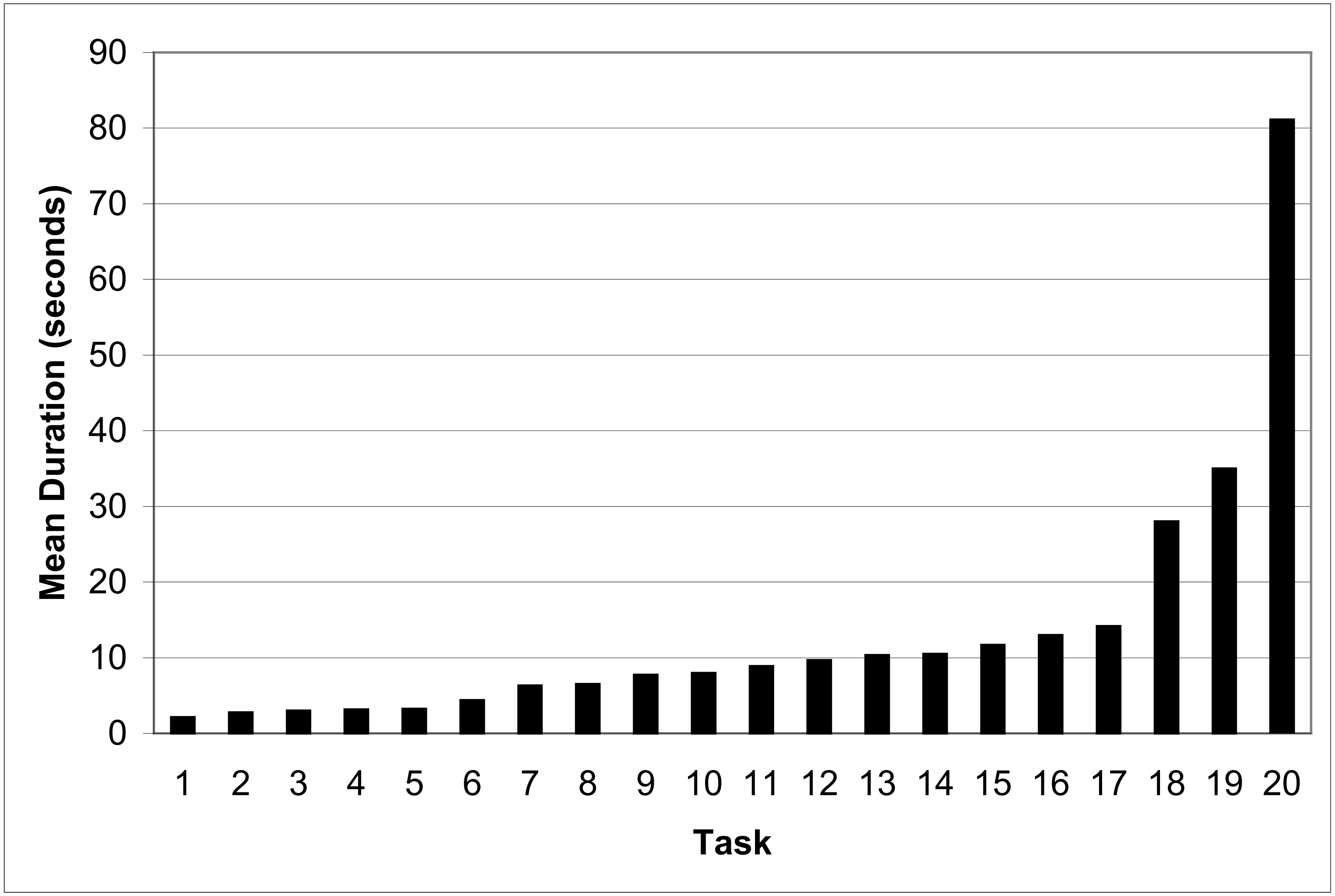
TaskObject ID
Task Object
UnitsOfMeasure
TableUnitsOfMe...
UnitOfMeasure
Explanation

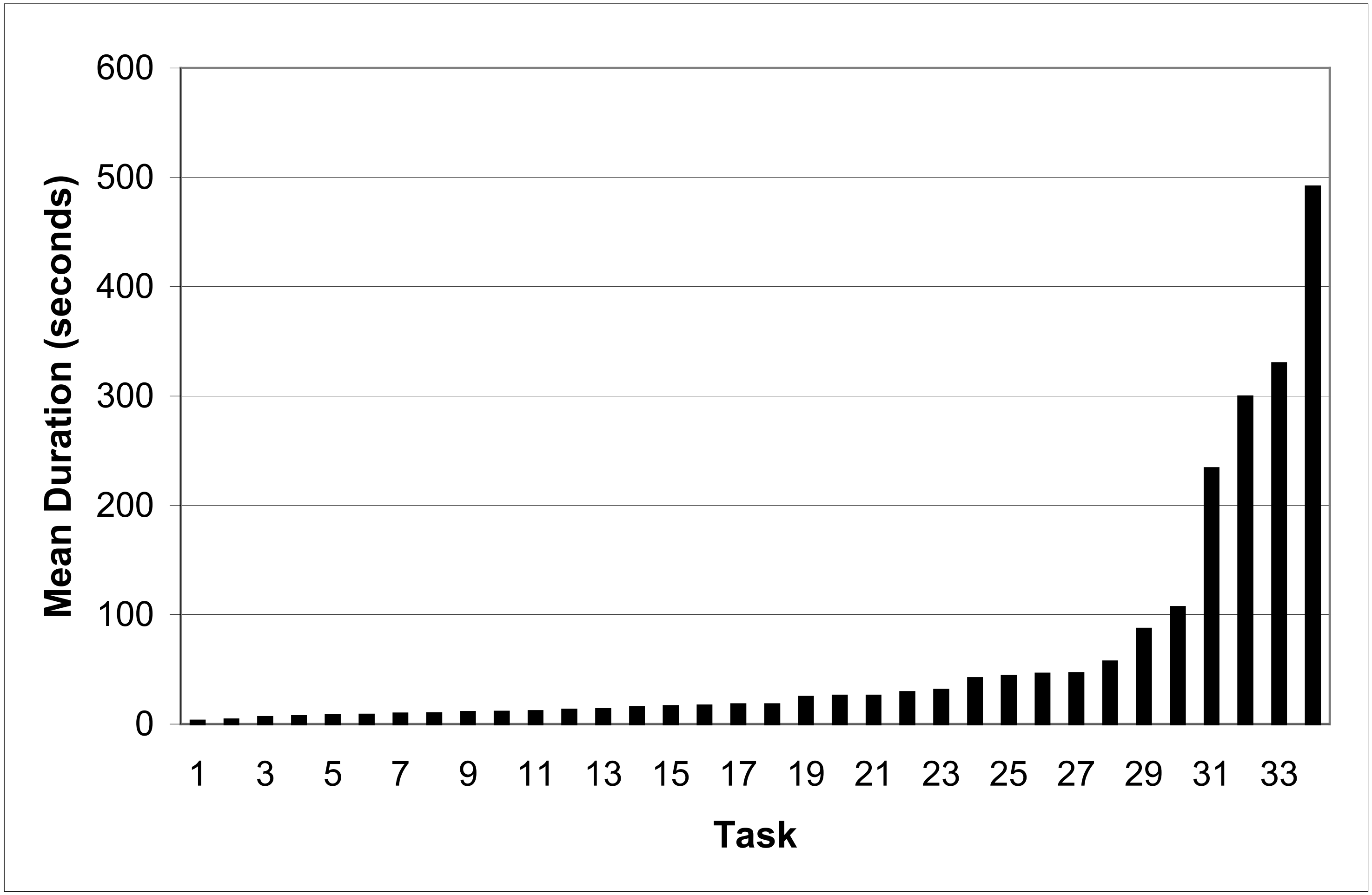


90
80
70
60
50
40
30
20
10
0
Duration (minutes)
Ginger Melon
Seitan Stir Fry
Whole Wheat Pasta
Peanut Wheat Hot Cereal
Soy Wheat Crepes
Asian Pesto
Recipe
Write
Weigh
Transit
Dead Time
Passive Time
Active Time

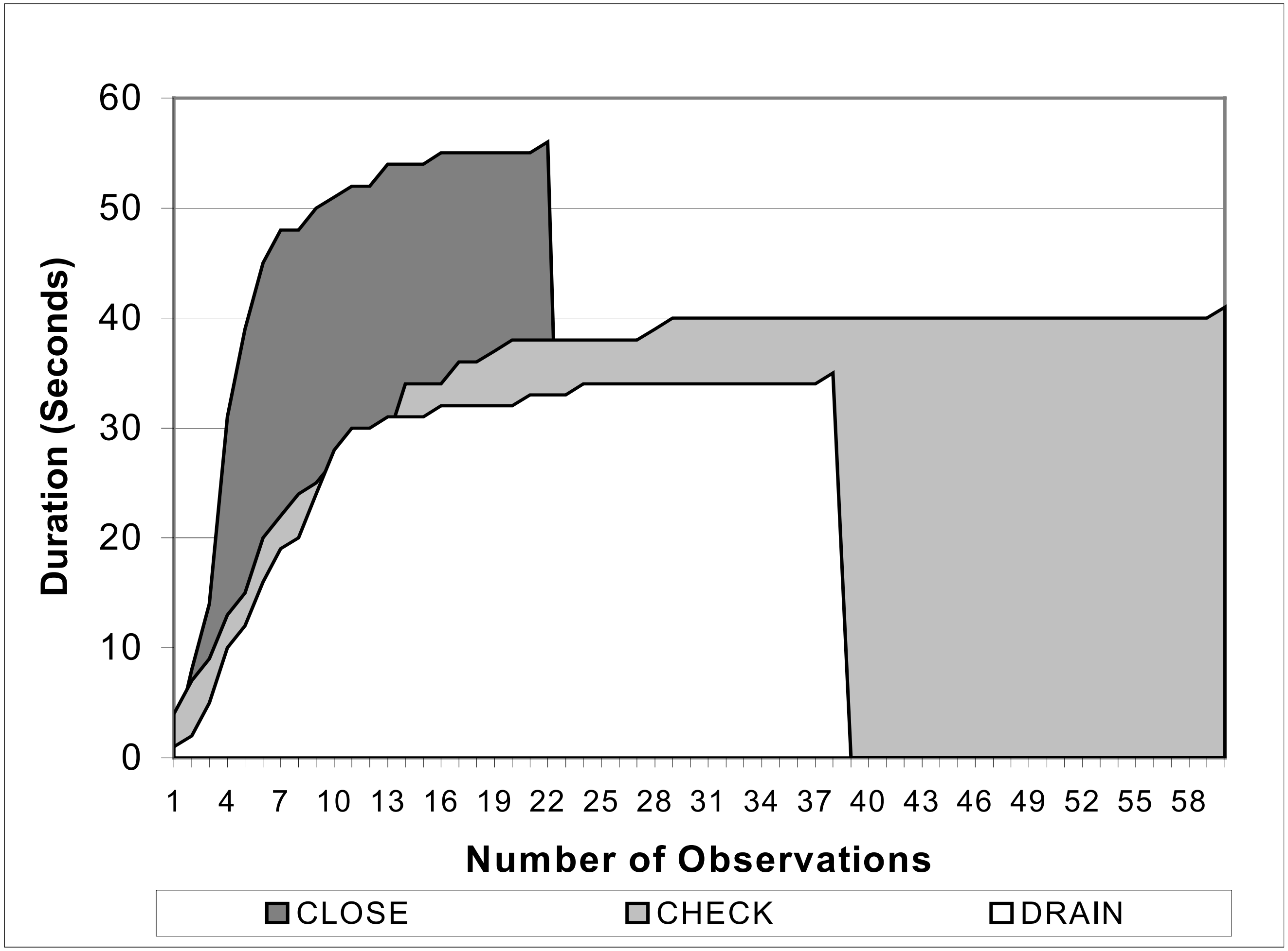


Duration (minutes)
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
Recipe
WRITE
WEIGH
TRANSIT
DEAD TIME
PASSIVE TIME
ACTIVE TIME

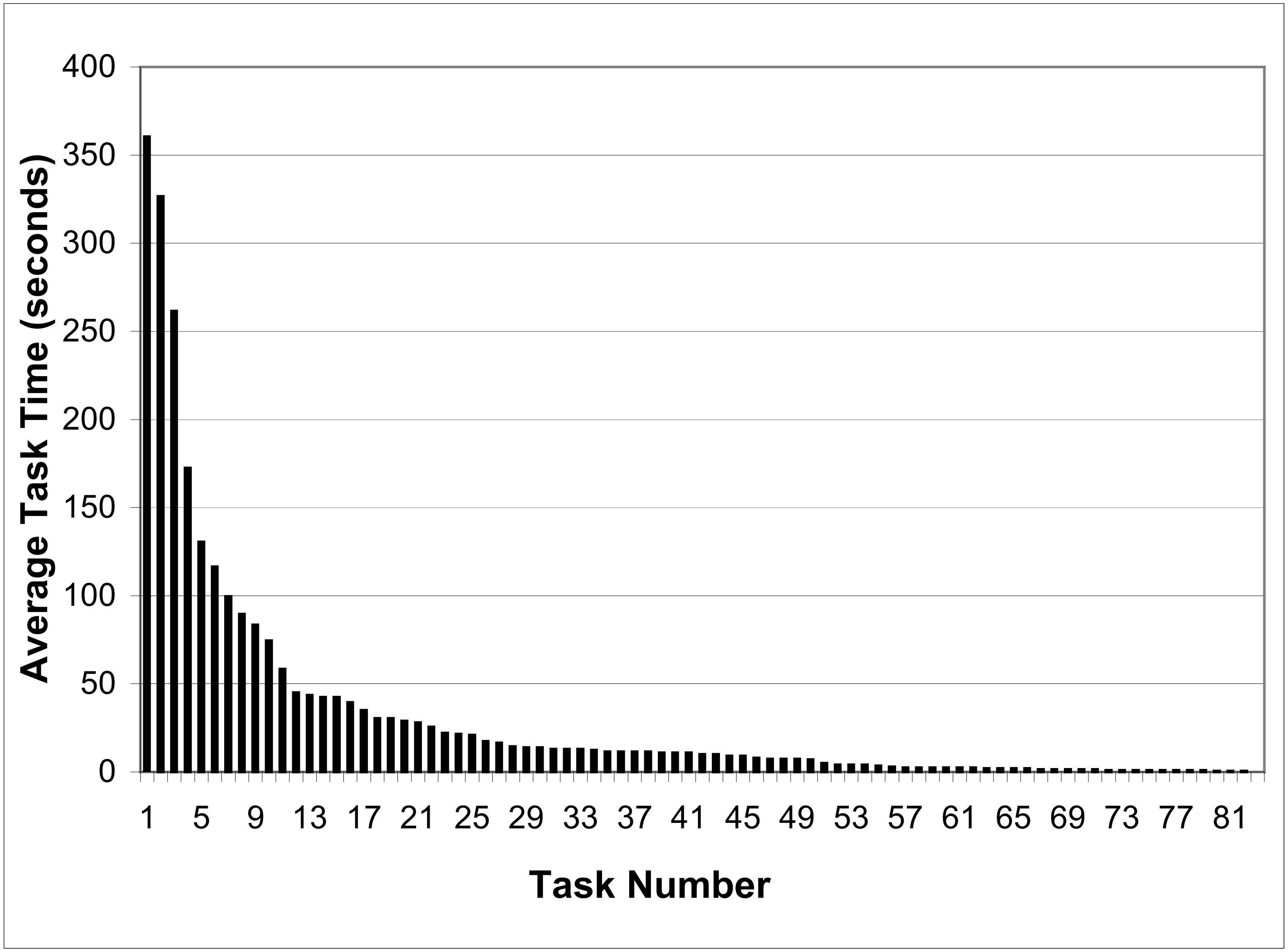

90
80
70
60
50
40
30
20
10
0
Mean Duration (seconds)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Task



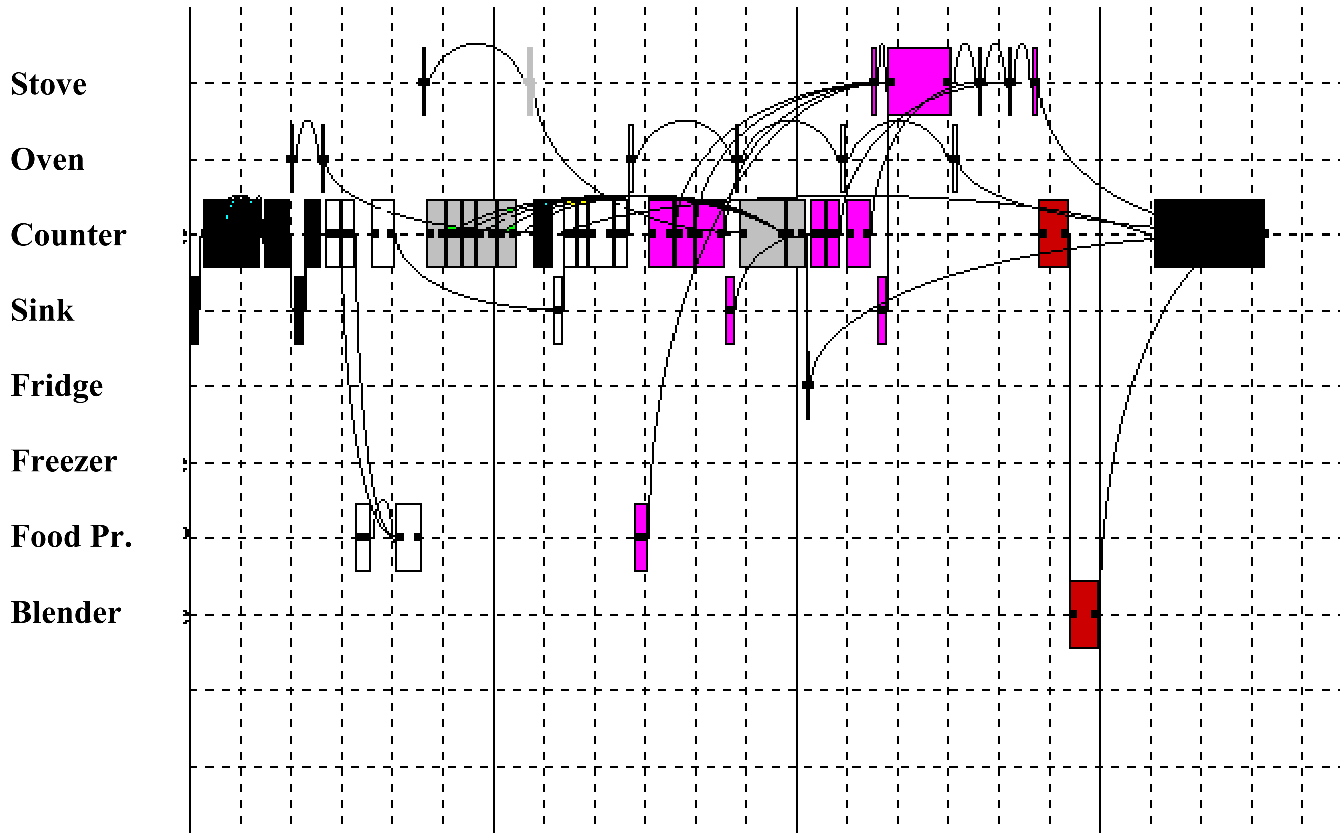
600
500
400
300
200
100
0
Mean Duration (seconds)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Task

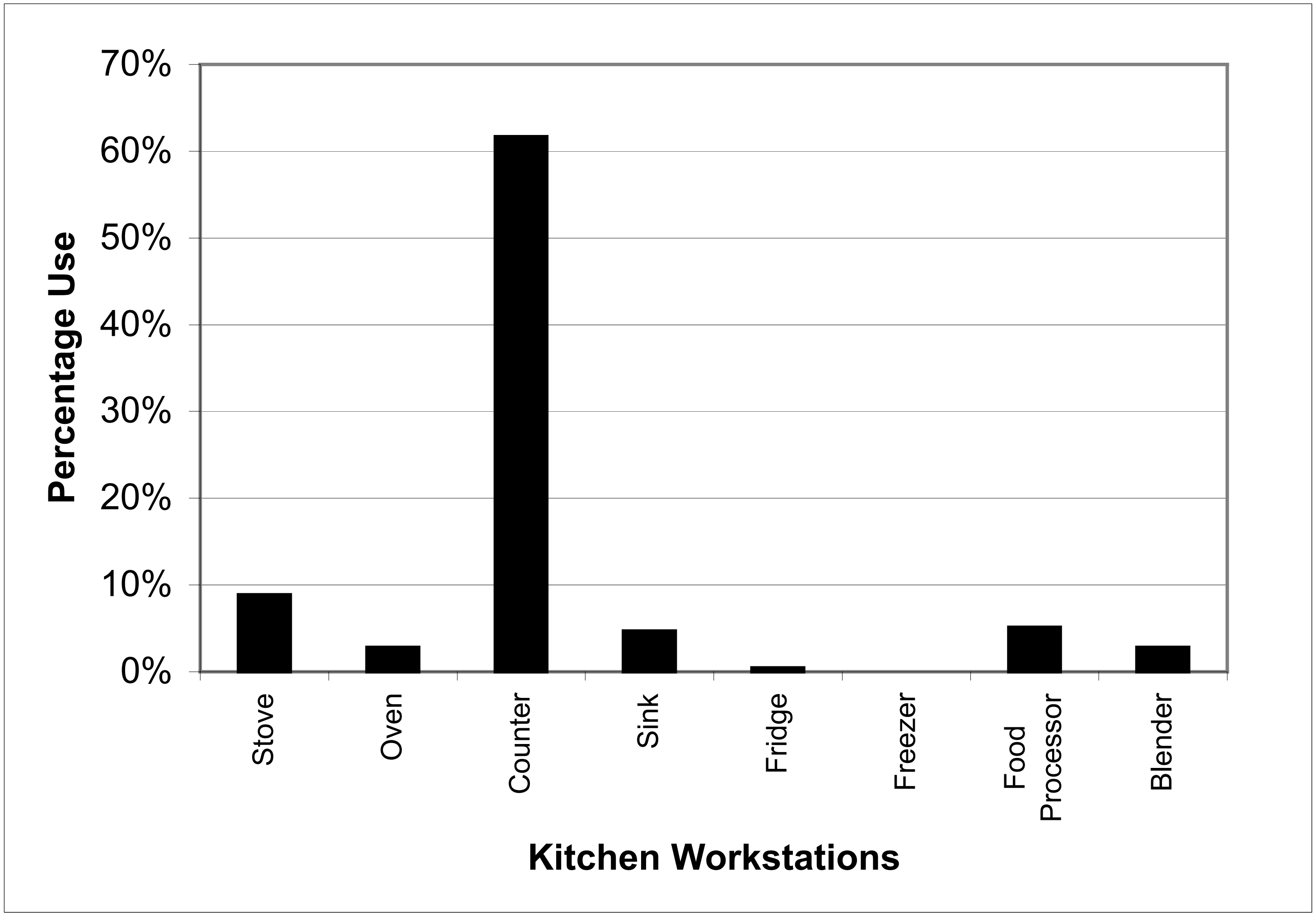


60
50
40
30
20
10
0
Duration (Seconds)
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
Number of Observations
CLOSE
CHECK
DRAIN



400
350
300
250
200
150
100
50
0
Average Task Time (seconds)
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81
Task Number


Stove
Oven
Counter
Sink
Fridge
Freezer
Food Pr.
Blender


70%
60%
50%
40%
30%
20%
10%
0%
Percentage Use
Stove
Oven
Counter
Sink
Fridge
Freezer
Food Processor
Blender
Kitchen Workstations