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WORK MEASUREMENT DECISION DIAGRAM DEVELOPMENT AND APPLICATION AT NASA'S KENNEDY SPACE CENTER

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ABSTRACT: This paper presents a decision flow diagram developed at NASA's Kennedy Space Center for the selection of the appropriate work measurement methodologies for Space Shuttle processing.

INTRODUCTION

A fundamental task for industrial engineers continues to be the establishment of time standards. Time standards are the amount of time required to complete a prescribed activity, following a set method, under particular working conditions. This information is used in government and industry for a multitude of purposes including scheduling, performance measurement, and cost analysis. [1,2]

RESEARCH OBJECTIVES

Research was conducted to evaluate four work measurement methodologies: stopwatch time study, predetermined time standard systems, historical data, and estimation. Other work measurement techniques were deemed impractical and eliminated from consideration. The following were the objectives of the research.

1) To determine the cost and feasibility of each of these four work measurement techniques for Space Shuttle processing at the Kennedy Space Center (KSC), a high technology environment with relatively low frequency and long cycle time operations.

2) To determine the factors critical for the selection of appropriate work measurement techniques for the working conditions and operational tasks at KSC.

3) To develop selection guidelines for the choice of the appropriate work measurement techniques for this unique working environment.

KSC ENVIRONMENT

The John F. Kennedy Space Center in Florida is the only active launch site for reusable manned space vehicles. Each reusable Space Shuttle Orbiter returns to KSC after completing its mission. The Orbiter is towed into the Orbiter Processing Facility (OPF) to be prepared for its next mission. It is then moved to the Vehicle Assembly Building (VAB) to be mated to the External Tank (ET) and two Solid Rocket Boosters (SRB's) before being transported to one of the two launch pads for final preparations. The preparations of the Shuttle's reusable Orbiters and SRB's have added an element of repetition to the workload at KSC that was uncommon during previous space programs. Some Shuttle processing is mission specific, such as payload preparations and installations, but substantial components of the processing recur each Shuttle flow. Examples of this include many Orbiter maintenance activities, system checkouts, and SRB refurbishment.

RESEARCH ISSUES

Work measurement techniques have been successfully applied for decades in a variety of industries. The working environment of Space Shuttle processing presents a challenging opportunity for setting time standards. The low repetition of the work is just one source of difficulty in determining the time standards. Since the majority of the processing tasks are performed only once per flow and there are only eight flows per year, the technician working the task may not have performed that particular operation in over a year.

An additional difficulty in establishing times for the numerous jobs is the variability of the overall work content. The sources of variations include mission specific requirements, in-flight anomalies from the previous mission, preventative maintenance intervals, changing engineering requirements, and design modifications. The work content of a particular task also varies due to differences between Orbiters and results of systems testing. The high safety and quality standards tend to govern the work pace as well as affecting the application of work measurement techniques. NASA is currently using time values estimated by engineers for scheduling work activities and is exploring additional work measurement techniques for use in scheduling, performance measurement, and quantitative analysis.

DECISION CRITERIA

Initially four criteria were considered for the evaluation of the work measurement techniques. They were feasibility of the technique, application cost of work measurement technique, consistency of the time standards, and accuracy of the time standards. It was decided to eliminate accuracy of the time standards from being a decision criteria. The use of the word "accuracy" in reference to time standards will often generate philosophical arguments concerning the ability of industrial engineers to determine the "true" work pace or level that should be used for comparison with the resulting time standards. It was assumed in the development of the selection process that factors would be determined to adjust the time values resulting from selected work measurement techniques to an appropriate time standard level. This eliminated the concern over accuracy of the time standards by the varying work measurement methodologies.

The feasibility of the technique was used in general to reduce potential work measurement techniques to the four previously listed. Feasibility was also considered for the ability of a particular work measurement technique to establish a time standard for a given work type. Examples of feasibility difficulties include the lack of historical data for tasks without technician involvement and applying a predetermined time standard system for detailed, flight critical inspections.

The remaining two decision criteria, application cost of the work measurement technique and consistency of the resulting time standards, tend to have conflicting results. Obviously one would want to minimize the cost of a work measurement system. Also it would be desirable to have consistent time standards, similar jobs should have similar time standards and the time standards for all of the operations should require the same degree of effort to complete. Inconsistent, variable time standards reduce the effectiveness of schedules and performance measures using the time standards. They can generate skepticism for the entire work measurement program. Unfortunately the better the consistency of the work measurement system the more expensive it tends to be.

SYSTEM SELECTION

The Space Shuttle contains twenty-four systems that are either mechanical, electrical, or fluid in nature. One of these fluid systems, the Orbiter's Main Propulsion System (MPS), served as the primary data source. The routine MPS operations are typically performed only once per processing flow. However, common tasks such as leak checks, system purges, and inspections occur frequently throughout the MPS operations.

The system has a variety of work characteristics. Some tasks are performed solely by the technicians; while others are performed by teams including technicians, inspectors, and engineers. The control of the operation can be by an engineer via a computer console in the Firing Room, by the technician on the shop floor, or a combination of the two. The Firing Room is used to monitor and manipulate on-board systems when the Orbiter is on the ground during testing activities. The MPS system selection for this research was made by NASA. MPS is considered a representative system as well as a critical component of the Space Shuttle processing schedule.

DIRECT OBSERVATION

The first methodology included in this research is direct observation. It is similar to stopwatch time study, but due to the limited repetition of the tasks the structure of the work measurement method was revised. The operational paperwork was reviewed prior to the observations, but the work elements within the tasks were not predefined. They were identified while the observation was in progress. Delays and foreign elements occurring during the observation were classified as separate elements and later excluded from the time standard value during the analysis portion of the study.

Effort ratings were not included in the direct observation analysis. Initially ratings were given for the task performance. Little variability resulted in the rating values among the observed technicians and tasks. In traditionally low technology work environments the pace tends to be dictated by the operator; with the work environment at KSC the pace of the work is slowed due to the lack of repetition, task criticality, and safety considerations. With this limited range of rating values, minimal information would be gained by including the ratings at the expense of introducing an unnecessary element of subjectivity, as with all ratings. Therefore, effort ratings were excluded from the direct observation.

ESTIMATION

Estimation is the second work measurement method to be included in this study. Two examples of this method will be used, the first being KSC's Computer Aided Planning and Scheduling System (CAPSS) which is the basis for scheduling the processing operations. The CAPSS time values are set by a group of engineers and are revised based on "as-run" experience. These time values are currently being used to develop the KSC Integrated Control Schedule and as such could be considered the current time standards.

Another KSC data source, a survey of Aft Shop technicians and supervisors familiar with the MPS system, was used as the second example of estimation in the study. The survey was conducted to determine the base task time duration, average setup time requirements, and the type of delays encountered for the various MPS operations. The respondents included shop supervision and technicians, each with up to ten years of MPS system experience. They were allowed as much time as necessary to complete the survey and reference copies of the work instructions were made available if desired. The respondents discussed their answers and reached a consensus of the time values for each task.

HISTORICAL DATA

Historical data is the third work measurement methodology included. The Shop Floor Data Collection System (SFDCS) at NASA provided this information. At the time of this research, the SFDCS had been in use at KSC for approximately nine months. Entries are made to the system, via a bar code reader, each time the assigned technician has a change in the job's status. Changes include starting the job, completing the job, halting the job due to a delay, or completing the work shift. The system records each entry's time, which can then be used to calculate the duration of the activity. For this research a report was generated from this system and the average time duration for each job was determined based on the edited data. When the task was not performed or not recorded in the system, no adjustment was made to the average time value. This resulted in varying numbers of entries being used to calculate the average time value. The number of entries ranged from one to five.

PREDETERMINED TIME STANDARD SYSTEM

The fourth and final method of setting time standards was a predetermined time standard system. There are numerous systems currently available including MTM, MOST, and MODAPTS. Varying levels of detail are possible with different versions of these systems. It was decided to only consider the higher level systems for KSC. The information necessary and application cost for the lower level systems were deemed prohibitive. The analysis was limited to a single system due to the cost of replicating the data with more than one predetermined time standard system. With these limitations, Maxi-MOST was selected for speed of application due to the lower level of system detail and the researcher's certification in the system. The selection of a particular system should not matter in a comparison of the use of a predetermined time standard system with the other work measurement methodologies.

WORK MEASUREMENT TECHNIQUE COST REQUIREMENTS

One of the decision criteria considered was the cost of establishing time standards by the four work measurement techniques. Cost was measured as the time required for engineers to set the time values by each method. The cost was divided into two categories: data collection and data analysis. Setup and maintenance costs of the systems were excluded. The setup cost would be small in comparison to the application cost and the maintenance costs would be proportional to the application cost. Cost requirements for the MPS operations are presented in Figure 1. The two estimation techniques and historical data had substantially lower costs than the other methods. The direct observation cost was more than double that of the other methods.

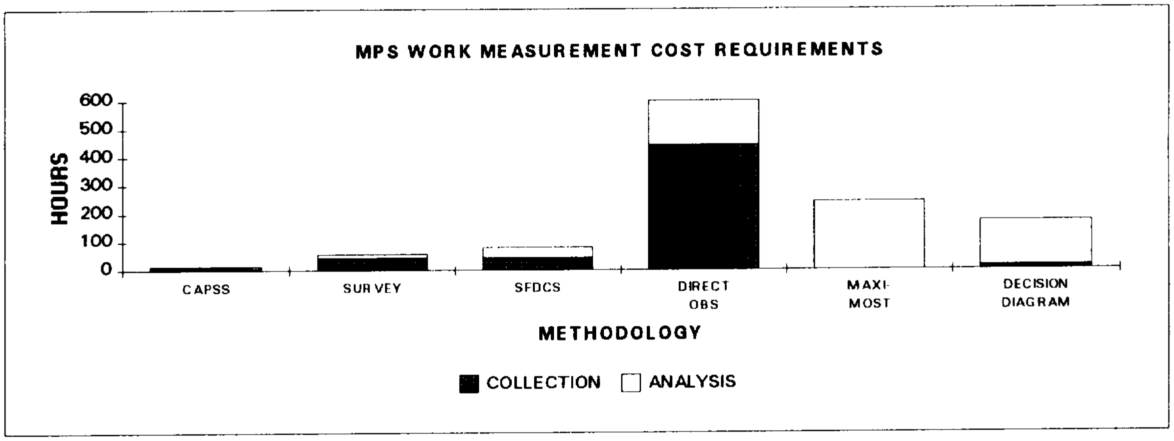

Figure 1.

VARIATION OF TIME VALUES

A second decision criteria was the variability of the time values by each system. Figure 2 highlights the potential sources of variance for each work measurement methodology. The time values and variance of the work tasks by each method were used as inputs to a computer simulation model of the MPS processing flow. The resulting makespan and variability are plotted in Figure 3. The estimation techniques and the historical data tend to have greater variances than the predetermined time standard system or the time study data.

WORK CLASSIFICATION

For analysis purposes the MPS tasks were divided into classifications based on characteristics of the work content of the operations. The following characteristics were used:

- Degree of technician involvement
- Degree of process paced activities
- Mental activities versus physical activities
- Use of specialized equipment
- Degree of care or accuracy required

DECISION DIAGRAM

The resulting time values by each work measurement methodology were compared for the MPS jobs. Different variances were observed for the varying work types. The results were used to develop the decision diagram shown in Figure 4. An attempt was made to minimize the variance and cost of the work measurement methodology for each work type. For example highly mental tasks such as inspection had a large variance regardless of the work measurement methodology used due to the variability between the technicians and inspectors performing the operations, so estimation was selected due to its relatively low cost for setting standards. However, inspection operations using magnifying devices such as borescopes tended to have a lower variance due to the device's influence on task pace. This combined with the difficulty of using a predetermined time standard system for some portions of these tasks resulted in the recommendation of Maxi-MOST supplemented with standard data from direct observation values. This approach was used for each of the work types to generate the decision diagram.

ANALYSIS OF DECISION DIAGRAM

A comparison was performed of the results of the decision diagram's selection of the various work measurement methodologies and the use of each method individually. As shown in Figure 1 the decision diagram had a moderate cost when compared the other methods. Figure 3 illustrates the decision diagram's performance with respect to the variability of the time standards.

CONCLUSIONS

This research shows that the use of a combination of work measurement techniques can allow the industrial engineer to systematically select the appropriate technique for varying work types. This approach attempts to provide the best methodology for the individual tasks by taking advantage of each work measurement method's abilities while minimizing the overall cost of the work measurement system. This technique can provide an innovative method for the cost effective application of time standards in areas currently not balancing the benefits of sound time standards with the cost of establishing them.

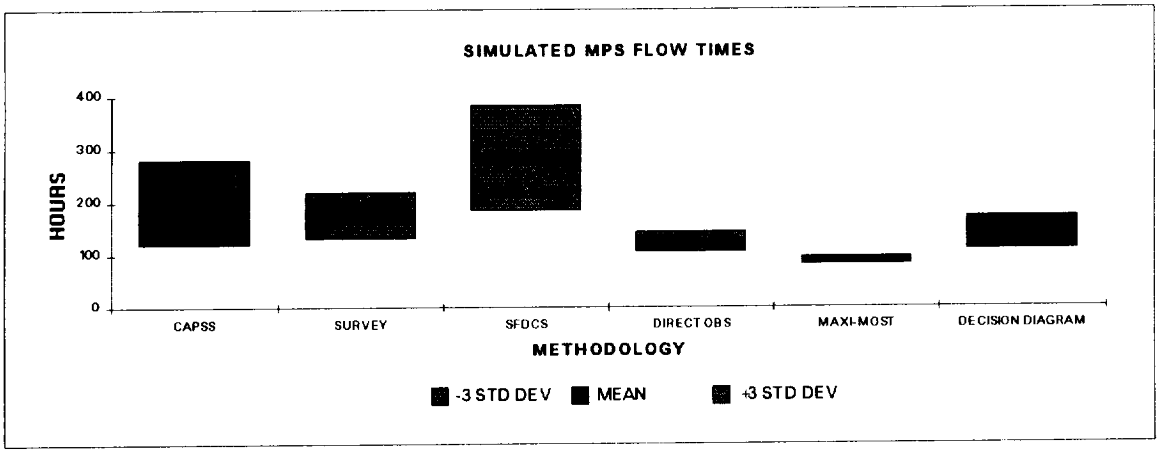

Figure 2.

SOURCES OF VARIABILITY

Sources \ Methodologies	Direct Obs. (Time Study)	Maxi-MOST (PTDS)	SFDCS (Historical)	CAPSS/ Survey (Estimation)
Inconsistent Work Method	✓	✓	✓	✓
Error in Recording Data	✓	✓	✓	
Small Sample Size	✓		✓	
Operator Pace	✓		✓	
Changeable Work Content	✓		✓	
Changeable Work Conditions	✓		✓	
Lack of Task Familiarity		✓		✓
Extreme Case Bias				✓
Varying Caution Levels of Est.				✓

Figure 3.

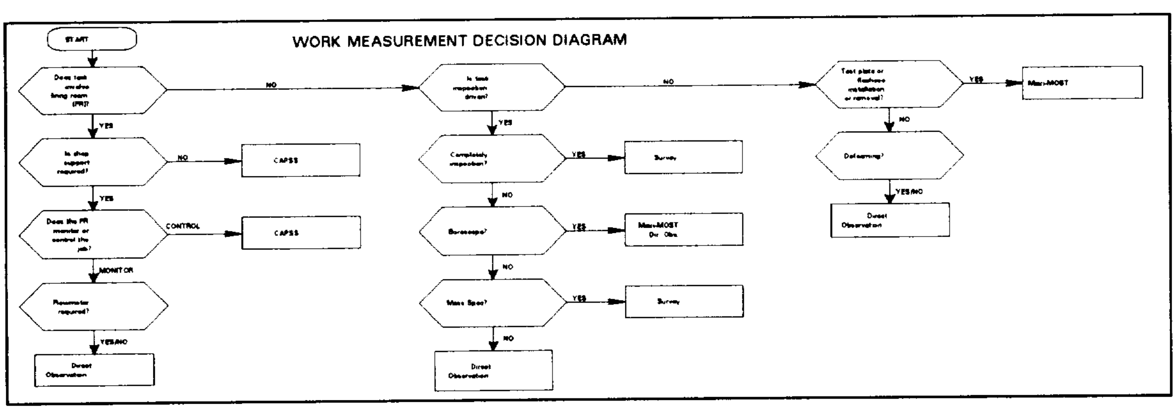

Figure 4.

Future studies will involve the application of this decision diagram approach to other systems as well as continued development for expansion to include other job classifications. These results are preliminary in nature and were developed using a small subset of Orbiter processing activities, but they do illustrate the potential for the selection of a combination of various work measurement techniques.

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BIOGRAPHICAL SKETCH

Susan L. Murray is a faculty member of the University of Central Florida's Industrial Engineering and Management Systems Department, Orlando, Florida. She is currently researching the application of traditional industrial engineering techniques in the high technology environment of NASA's Space Shuttle Processing at the Kennedy Space Center. She has a BSIE degree from Texas A&M University and a MSIE degree from the University of Texas at Arlington. Currently she is completing her Ph.D. in Industrial Engineering from Texas A&M University. She is certified in MOST, Maxi-MOST, and MODAPTS and is a registered Professional Engineer in the state of Texas with over seven years of aerospace and defense industry experience. Ms. Murray is a member of the Institute of Industrial Engineers, Human Factors & Ergonomics Society, and Alpha Pi Mu.

Amanda M. Mitskevich has been employed by NASA as a Lead Industrial Engineer for two years in the Shuttle Operations Analysis Office at the Kennedy Space Center, Florida. Previously she spent five years in Space Shuttle Logistics. She holds a Bachelor's degree in Industrial Engineering from the Georgia Institute of Technology and a Master of Science Degree in Engineering Management from the University of Central Florida. She is the Secretary/Treasurer of the Space Coast Chapter of the Institute of Industrial Engineers.

Joseph J. Pignatiello, Jr. is an Associate Professor in the Department of Industrial Engineering at Texas A&M University, College Station, Texas. Dr. Pignatiello received his B.S. from the University of Massachusetts and his M.S. and Ph.D. from Ohio State University. His research and teaching interests are in the area of quality engineering, including statistical process control, design and analysis of experiments for quality improvements and applied statistics. Dr. Pignatiello is a member of the Institute of Industrial Engineers, the American Society for Quality Control, the American Statistical Association, Alpha Pi Mu, and twice recipient of Ellis R. Ott Foundation award for his research publications. He was also a recipient of the Collegiate Teaching Award, the University of Iowa's highest award for excellence in teaching.

Timothy S. Barth is a Lead Engineer with the Shuttle Operations Analysis Office at the Kennedy Space Center, Florida. He is project manager for a number of projects dealing with productivity improvement of ground processing activities. He holds a Bachelor's degree in Mechanical Engineering from the University of Nebraska and a Master of Science Degree from the University of Arizona in Aerospace Engineering.

William W. Swart is a Professor and Chair of the Department of Industrial Engineering at the University of Central Florida, Orlando, Florida. He received his B.S. in Industrial Engineering from Clemson University and his M.S. and Ph.D. from the Georgia Institute of Technology. His industrial experience includes positions with International Paper Company, DuPont, and Burger King Corporation. At Burger King he was Vice President of Operations Systems and Vice President of MIS.