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The Work Crew Performance Model: A Method for Evaluating Training and Performance in the Mining Industry

By W. J. Wiehagen, G. T. Lineberry, W. E. Lacefield,
M. J. Brnich, and L. L. Rethi



UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to Units of the International
System of Units (SI)

Abbreviation	Unit of Measure	To convert to—	Multiply by—
ft	foot	meters	0.30
st	ton	metric tons	0.907
min	minute	—	—
cu ft	cubic foot	cubic meters	0.02832
mph	mile per hour	meters per second	0.447
t/m	short ton per minute	—	—

THE WORK CREW PERFORMANCE MODEL: A METHOD FOR EVALUATING TRAINING AND PERFORMANCE IN THE MINING INDUSTRY

By W. J. Wiehagen,¹ G. T. Lineberry,² W. E. Lacefield,³ M. J. Brnich,⁴ and L. L. Rethi⁵

ABSTRACT

The Work Crew Performance Model (WCPM) seeks to define performance variability within similar tasks of an underground work crew and relate observed variability to a cost consequence. Performance variability is described using work site observations to determine the adherence to job elements contained within a standard operating procedure.

Key components of the WCPM include (1) job definition through task analyses and the ranking of job elements by perceived cost consequence, (2) observational techniques for establishing performance baselines by measuring adherence to safe and proficient job procedures, and (3) cost linkages between adherence to task procedures and measures of consequence for noncompliance.

Data presented within this report were obtained through the study of shuttle car operation in an underground mine in Appalachia. Observed adherence to safe and proficient job procedures by operators matched well with the consensus profiles (measured through a nominal group technique) with mining personnel. It was also found that experienced operators consistently outperformed less experienced, incidental operators.

These findings imply potential use of the WCPM as a practical procedure for thinking systematically about the choices available to reduce performance variability. Field application of the model can offer useful data to evaluate training and financially support performance improvement strategies that can be tested for their ability to reduce human error.

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INTRODUCTION

Training is broadly intended to enhance the profitability of organizations and to improve the quality of work life (1).⁶ Although the training literature abounds with anecdotal evidence of its value, few studies have attempted to tie that training specifically to worker performance and to the effects of improvements in performance on corporate profits, or to demonstrate the value of safety training and the length of its effectiveness (2-3). Only recently have a few studies appeared that have measured the effects of intervention strategies on on-the-job performance (4-7). Even fewer examples appear in the literature addressing the broader concept of integrating programs of selection, training, and on-the-job performance (8-9).

Hale's (10) review of the safety training literature and practices in the United Kingdom calls attention to the difficulty inherent in evaluative safety training research confounded by the persistent and problematic use of injury data as the primary measure of effect. Broader reviews (11) of assessing the returns to industrial training have commented on the relative sparseness of the literature. Often, evaluation studies are notorious for treating the intervention as a unitary variable, operating in isolation, and for evaluating the effect of training programs using participant feedback as the sole measure of effect. While participant feedback is useful to the trainer, it may not have much impact on what is learned nor on desired changes in work performance. The few studies that attempt to assess employer-sponsored safety and skills training are often noted as being subjective, lacking standardization, and being unable to attribute causation to training (10-11).

Adding to the frustration is the fact that it is difficult to assess training's exact economic contribution to organizational effectiveness, especially in terms of a return-on-investment measure (12-13). Furthermore, recent work concerning assessment of the effectiveness of training and the estimation of training costs (14-17) focuses on the evaluation of managerial training; much less research attention has been paid to skilled manual training.

The difficulties inherent in the evaluation of training are signified by the general industry's willingness to take training outcomes on faith, that is, by not establishing empirical links between training and profit or between training and safety. Despite this, safety and skills training activities have long been recognized as essential elements in programs for reducing injuries and improving productivity within the minerals industry (18). One group (11) asserts that "perhaps the fact that training exists and persists should be taken as *prima facie* evidence that, at least in the minds of those who make the training decisions, the benefits exceed the costs."

Traditional, bottom-line measures (productivity and injuries) of training effect are riddled with contingencies that make them of limited usefulness in justifying long-term performance improvement strategies. Examples of confounding factors include changes in mining conditions and systems over time, the effects of extended practice and day-to-day reinforcements, reporting discrepancies; technologic and human factors improvements, interdependence of other crew members, including the supervisor; and machine maintenance. Evaluations of training effectiveness are especially problematic where experienced miners and machine operators are involved. A high degree of face validity, within the context of the workplace, is particularly important for criterion measures useful to a veteran work force. Training evaluation not only needs to offer insight to training sponsors and developers, but must have value to those receiving the investment.

A book entitled New Developments in Worker Training (11), has recognized the confusion in identifying the bottom line objectives of training and the technical progress toward these objectives by noting simply: "it is perhaps easier to trust [the return on training] than to measure." Kirkpatrick (19) suggests that the important issue in training evaluation might embody a concept of *evidence*, not *proof*.

These remarks imply that more useful and realistic training and performance assessment methods need to be developed. The issue is not whether to evaluate, but how to target the suitable criterion outcome measures when evaluation is done. Typical bottom-line evaluations of training and other performance improvement strategies in the mining and other industries tend to focus on improving both profit (measured through productivity) and the quality of work life (measured through injury frequency, severity, and health risk) (20-23). More attention might be given to the use of meaningful dependent variables that reflect cost-benefit components of investments in performance improvement strategies. In addition to training, these other strategies can include job design, selection and placement, and supervision, among others.

Part of the mission of the U.S. Bureau of Mines (USBM) is to conduct research that can enhance the quality of mine training. The goal of this research effort was to formulate a strategy for modeling an individual worker's performance and for linking that performance to organizational accomplishment. The Work Crew Performance Model (WCPM) represents one approach that holds promise from the viewpoint of the individual, the work crew, and of the organization. The premise maintained throughout this research is that economic and performance analyses can be applied to mine training as well as to other work crew interventions. The foundation for economic and performance analyses is objective and reliable data.

⁶Italic numbers in parentheses refer to items in the list of references preceding the appendixes.

BACKGROUND

The term "training" is often used in varying contexts. For this report, training is defined as any activity that develops a capability that does not yet exist or that reinforces and heightens an existing level of skill. As such, training implies increasing competence with respect to the task. Increasing competence implies improved performance, generally defined at some broader level that relates individual activity to the organization's goals. Improved competence, in turn, cannot be measured without some means of evaluation.

An earlier USBM investigation (24) established the need for better methods of training and assessment, closely linked to job characteristics and productivity indicators. It called attention to the central role of front-line supervisors and corporate training personnel, both in initial training and in follow-up assessment of employees' job-related skills. A conceptual model was offered addressing underground equipment operator competence and how this proficiency might be measured within the context of a work crew. A visual detection method, loosely guided by a model developed by the U.S. Department of Transportation (25), was offered to profile error patterns defined as a deviation from the standard operating procedures (SOPs). Findings of this preliminary investigation, which provided groundwork for the WCPM, are summarized in appendix A.

A second USBM publication (26) described the WCPM in detail. A limited review of training effectiveness research illustrated many of the difficulties in relying on traditional, broad based measures of training effect. It emphasized the desire for linkages among training (measured by adherence to defined work procedures) and its impact on individual equipment operator performance and, ultimately, achievement of the work crew. The WCPM, conceptualized in figure 1, is designed to couple training and performance more tightly at the individual, work crew, and organizational level. The relevance of the WCPM, particularly for an experienced work force, was noted. Appendix B provides additional underpinnings of the WCPM by noting the difficulties in using injury and productivity measures in assessing training impact. It concludes with a rationale for the use of behavioral measures to determine training effect.

Important components of the WCPM is both its reliance on *learning* from a veteran work force and using that information to *reinvest* in strategies to enhance quality output. Quality can be measured along two dimensions: *what* (or *how much*) is produced, and *how* (e.g., *how safely*) the product is mined. The WCPM ranks behavioral measures relevant to the operator's task by assessing the relationship of errors (i.e., performance variability in critical job tasks) to the primary accomplishment of the

job. In the case of the shuttle car operator, that accomplishment might be to minimize the continuous miner wait time for an empty shuttle car; in the case of the continuous miner operator, the accomplishment might be to maximize load time as a percentage of shift time.

To illustrate this point, for the shuttle car operation, SOPs typically recognize as few as 50 to over 100 specific items. Only a portion of these, however, define performance errors that *significantly* impact the operator's job accomplishment. The practical utility of these lists is limited without the associated information about the relative frequencies of tasks or subtasks, and the probabilities that occurrence of errors will have a direct and important impact on the safety and productivity of the work crew. Without this information (i.e., a norm), one could expect significant variability within the job task, dependent upon individual perceptions of accomplishment, task experience, risk taking, the design of the equipment, work procedures, and the management system.

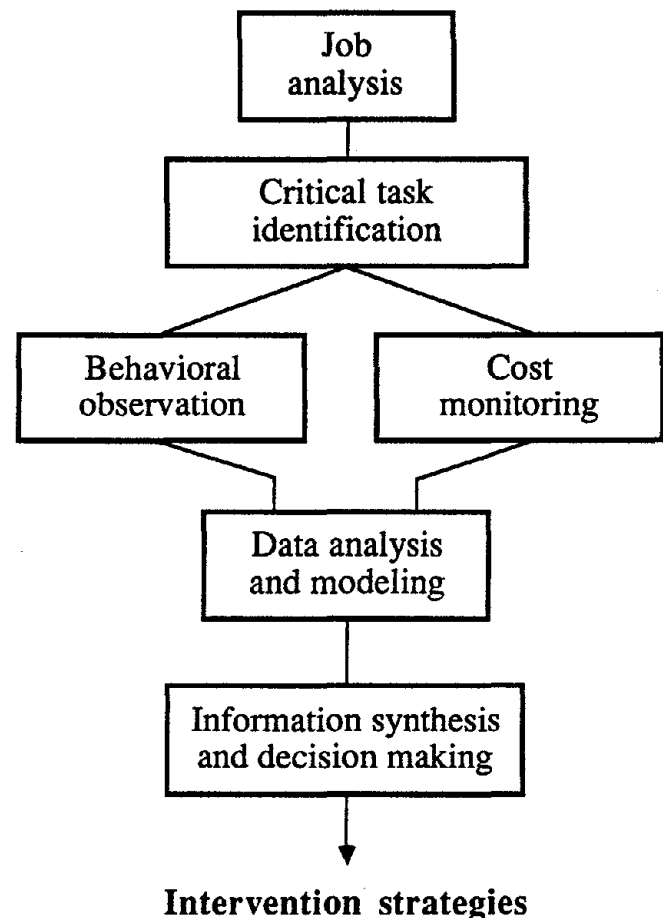


Figure 1.—The Work Crew Performance Model.

Moreover, the ranking of observable cues is often mine-specific. For example, the importance of the rating of the shuttle car operation subtask later described as "prevents load from piling too high and 'roofing' or catching overhead cables" can vary in relation to shuttle car geometry, to mining height, or to cable placement practice.

The research issue, then, becomes one of identifying and ranking, by costliness of consequences, observable cues that indicate whether job accomplishment can be attained with minimum negative impact on safety and productivity. The model should not only identify errors that can be linked to injuries, equipment damage, and

downtime delays, but also should suggest the range of interventions that might be implemented to enhance performance. Obviously, intervention strategies often lie outside of what is considered traditional job safety or skills training. These can include job redesign, ergonomic design, recruitment and selection, work allocation, reward systems, feedback, and coaching. Conceptualization of the WCPM began with the goal of developing a methodology to distinguish between exemplary and average performers, but, as will be detailed later, it has the potential to be a much more powerful planning and evaluative tool for decision making and resource allocation.

THE WORK CREW PERFORMANCE MODEL

APPROACH

The WCPM seeks to integrate procedures for conducting job analyses, evaluating worker performance, and using cost information as a basis for decision making within the context of organizational goals. Since profit is directly tied to production cost (dollar per st), key variables used to define, measure, and evaluate worker performance should emphasize those specific behaviors that can have a marked impact on unit cost. Of specific interest are behaviors under an individual crew member's control that can be described in terms of deviations from a criterion (e.g., SOP) and corresponding probabilities of downtime, injuries, production decrement, and/or damaged property. There remains a fair amount of disagreement among researchers as to which of these criteria to use when evaluating training programs (27-28). The USBM's research efforts have bridged the gap between the economist's view, which focuses on outcome measures (productivity, injury data, downtime, and product quality) and the psychologist's view, which focuses on employee behavior (observable, and therefore recordable, task performances).

Implementation of the WCPM includes provisions for: (1) job definition and the ranking of job tasks based on information from mining personnel expert in the operation, repair, and maintenance of the equipment; (2) observational techniques to establish performance baselines by measuring adherence to operating procedures; and (3) linkages between observed performance profiles and resultant costs (measures of injuries, downtime, and maintenance overhead).

The WCPM approach is unique in that it seeks to integrate these typically exclusive provisions within a work organization. For example, common methods used to define job performance and to evaluate operators' work behavior have been based on checklists of appropriate or desired behaviors. These lists are often reduced to a SOP or Job Safety Analysis (JSA). However, these lists are

typically divorced from day-to-day records of production downtime, lost-time injuries, system inefficiencies, and maintenance overhead. Sometimes forgotten is the notion that these formal checklists were made up; they were probably prepared for a purpose, and might better serve as a beginning, not an end.

The WCPM provides a framework for integrating various types of data and using information from a variety of sources to guide decision making *empirically*. The model advocates the more functional use of checklists. An integrated approach also allows the WCPM to be used as an evaluation and problem solving tool with veteran as well as novice equipment operators. Within this context, training and therefore learning, is an on-going, iterative process, not limited to administrative or regulatory requirements.

ASSUMPTIONS

The WCPM rests on a set of assumptions about the nature of the worker and the job. A key assumption is that, for the most part, individuals make errors without intent to incur personal injury, induce downtime, diminish production, or damage property. In other words, employees come to work to be productive. Nevertheless, performance differentials between individuals are often nebulous and ill-defined (29). The WCPM does not simply attempt to classify individuals as exemplars or average performers, but seeks to attend to those common errors or differences in error profiles that can markedly affect cost. Use of the WCPM to profile operational errors and to justify the selection of an intervention strategy relies on the following realistic and somewhat obvious assumptions regarding work:

1. All individuals will make errors, regardless of the level of training or experience. Error rates of individuals are dependent upon a host of things that may or may not relate to the quality of initial training.

2. Error rates can be observed, measured, and managed. Although there may be cognitive components such as errors in judgment and decision making, resultant behaviors and outcomes can, in most cases, be observed and quantified in terms of cost consequences to the organization (e.g., profit-loss) and to the individual (e.g., effort expended).

3. The measurement of crew output, with meaningful implications for individual task performance (including design), is significantly more complex than measuring the output for isolated tasks, such as a welder or a beltman.

Thus, at a minimum, the WCPM can be thought of as a visual detection method to identify critical components of complex job performances such that wide differentials in performance for high-consequence tasks are identified and treated. *Within this context, it is likely that the total set of errors of the exemplar can exceed the error rate of the average operator. However, the types of errors committed may be quite different.* The ability to define and discriminate error profiles within and across crew members is the essential element of the WCPM. It recognizes and seeks to address the complexities of crew performance and attempts to define and link error profiles of individual crew members to crew output and organizational goals.

COMPONENTS

The multitude of activities necessary for safe and productive shuttle car operation can be organized into hierarchies of task and subtask categories, with descriptions of the skills involved and the typical working conditions for each task. A performance criterion for each category, based on typical, practical, or ideal work standards, might also be included in the job analysis (30). Work site observations are used to systematically assess performance on each task and subtask with significant cost consequence. Cost linkages are then made possible, whereby observable behaviors are tied to unit cost. Together, *job definitions* (including the ranking of critical tasks), *behavioral observations*, and *cost linkages* form the tenets of the WCPM. These data offer a foundation for analysis of the effect of field-based interventions to reduce the variability within critical job elements.

Job Definitions

Examples of major task categories for shuttle car operation might include preshift inspections, tramming, loading, idle-time activities, and others, whereas a subtask in the tramming category might be switching the headlights to the opposite direction after reaching the continuous miner. However, as has been pointed out previously, the practical utility of these lists is limited without associated

information about the relative frequencies of these behaviors and the probabilities that deviations in performance will have a direct and important impact on safety and on the unit cost of the underground mine section. For these and other reasons, a comprehensive model of worker or work crew performance must look ahead to the consequences of performance errors and the accumulated effects of this variability on the quality of output of the work crew. In this context, an error is simply "a failure of human performance; the performer is pursuing some objective [(task completion)] and either does not achieve it or departs significantly from the acceptable path towards it (31)." Cherns (32) has gone so far as to couple errors and accidents by defining an accident succinctly as "an error with sad consequences."

Behavioral Observations

Work sampling, a method first described by Tippet (33) in 1935, was used to study the state of activity of machines in a textile mill. In the context of this research, however, "behavioral observation" is the preferred term, since it is, in effect, work sampling used for monitoring or measuring human behavior. The method, which the military refers to as the job sample approach (34-35), is a technique in which multiple, randomized observations of human behaviors are made over a period of time to facilitate quantitative analysis of a task. The percentage of observations recorded for a particular activity (or error) is a measure of the percentage of time during which that activity (or error) actually occurred. The method has been used, in its simplest form, as a managerial accounting technique to ascertain if time and effort are being allocated efficiently in a single-period study (36-39) and as a proxy for estimating worker productivity (40-46).

The labor-saving advantages of random sampling over continuous observation are clear. The assumption made in electing to evaluate task and subtask proficiency through a randomized sampling procedure is that the sampled behaviors represent actual performance (39, 47).

Although work sampling procedures can provide detailed and accurate estimates of proficiency, it requires observers with knowledge of the nature of the job or task and experience to make sound judgments about the quality of observed performances. In addition, observers should be persons whose presence is unobtrusive in the workplace. Although observational methods are vulnerable to the fallibility of human perceivers, they remain the only effective way to assess complex behavior in highly variable work settings (7, 42).

In underground mines, the face boss may be the individual best suited to observe members of the work crew. Repeatedly observing and noting an operator's performance on more than just a few steps during day-to-day

operations would most likely strain the supervisor's time and opportunity. As a result, supervisors, when required to do so, most often evaluate performance at the task level (e.g., tramming, loading, etc.) rather than at the subtask level.

Assuming enough observations are made, evaluating performance at the task level can yield some estimate of proficiency, adequate for administrative purposes. Too often, however, this sort of aggregate information is of little value to the employee without further attention to the components of proficient performance and the identification of cost consequences of critical errors. Errors are always made at the *subtask level*, yielding information that reflects on task proficiency. An increasing awareness of errors and consequences provides opportunities to test solutions involving training, equipment design, or job procedures.

Cost Linkages

A key issue for WCPM development concerns the identification and ranking of observable behaviors (error profiles) that affect cost. Reducing errors is analogous to reducing variabilities within the task. In the case of the shuttle car operator, factors that have negative impacts on miner wait time include behaviors that lead to injuries, downtime, excessive maintenance, diminished production, and property damage. Once these factors are identified, the task becomes one of (1) enhancing the supervisor's and the workers' abilities to discriminate between significant and less significant performance errors by

associating those errors with their cost consequences, and (2) identifying performance improvement strategies to reduce the frequency of costly errors, as discussed in the following subsection.

Recommendations for Intervention Strategies

Several intervention strategies can result from the WCPM methodology. The ranking of tasks and the collection of observational data offer an estimate of proficiency for tasks and subtasks and seeks to link proficiency (or error) profiles with likely consequences. It follows that treatments can be categorized into several areas:

1. *Training and performance feedback* provides information to crew members regarding the expected gain attainable from small, incremental improvements in subtask performance. Discussing alternative interventions with experienced machine operators can lead to more permanent design solutions, such as those associated with ergonomic design, job procedures, and the conditions of the workplace.
2. *Work system design* includes such considerations as layout of the section, cable handling policy, and decisions regarding upgrading roadways.
3. *Administrative procedures* include those associated with work allocation, assembling work crews and scheduling major task activities (such as belt moves), identifying training needs, rewarding performance, and reporting downtime data to better reflect contributing factors associated with injury risk and production interruptions.

FIELD APPLICATION OF THE WCPM

A series of preliminary field studies was carried out with the assistance of a medium-sized mining company in eastern Kentucky. These studies provided baseline data for three key components of the WCPM.

Task Analyses. Shuttle car operator job requirements. Time study data.

Performance Evaluation. Visual observations of three regular and three incidental shuttle car operators.

Cost Linkages. Productivity data by mining section and by shift. Mechanical and production downtime rates. Production time lost.

Primary objectives for the field work included determining whether differences in performance error rates among operators could be detected visually through behavioral observation and whether operator or crew error profiles could be related to historic records of interruptions in production (e.g., injuries, mechanical downtime, and

property damage). Also of interest was how the WCPM could be used as an aid to section supervisors and mine management in evaluating equipment operator performance and in establishing a cost base for treatment. However, before these questions could be addressed, an accurate description of shuttle car operation was required.

TASK ANALYSES

A description of job performance requires attention to four components of the activity being described (1) the tasks or activities being accomplished, (2) the prerequisite knowledge and skills necessary to carry out the activities, (3) the conditions and circumstances under which the work is to be conducted, and (4) the performance standards or expectations for successful task accomplishment (48-49). Moreover, the analysis needs to be carefully validated to ensure that machine operators, supervisors, managers, and researchers can reach and maintain a relatively high level

of consensus regarding the correctness and appropriateness of the performance description. The WCPM extends the analysis to include appraisals of the consequences or costs of performance errors. This step connects operator proficiency to organizational variables at a more useful level of analysis for the crew member, the section supervisor, and mine management.

The Shuttle Car Work Environment

The particular mine where the preliminary field studies took place is a multisection mine located in the Stockton and Coalberg Seams in eastern Kentucky. The section under study is in the Coalberg Seam, with an average coal height of 7 ft. It is served by two Jeffrey⁷ continuous miners and three Joy 10SC shuttle cars. Two cars are of standard design with left side compartments; the third is off-standard with a right side compartment. The mining section operates two shifts per day with two regular shuttle car operators assigned on each shift. When the third shuttle car is needed, an incidental operator, such as a scoop operator, block layer, or section supervisor, runs the machine. When all three machines are operated, which is a relatively rare occurrence, two cars serve one continuous miner; the third serves the second miner. At the time of data collection, the section mined approximately 1,200 raw tons (st) of coal per shift. At the time of the study, the section's productivity was approximately 50 pct higher than the national average and perhaps 25 to 30 pct higher than similarly equipped and comparably staffed underground coal mining sections in the area. Of note, the mine had not experienced any lost-time injuries to shuttle car operators (while operating the shuttle car). This was important as management recognized that the absence of injuries did not necessarily imply the absence of problems, nor the potential for serious injury.

Shuttle Car Operator Activities

Drawing on past research, training materials, SOPs of other companies, and job descriptions for shuttle car operators provided by the cooperating mine, an initial list of 112 separate operator activities was compiled (50-51). This comprehensive list was grouped into the six major task categories. The categories were defined during the development of the observation checklist. The list was then screened for redundancy, modified, and condensed to reflect only those behaviors that were observable and appropriate for the operations at the cooperating mine. Fifty-eight distinct activities were retained and used

to guide behavioral observations and the Q-sort, nominal group process studies.

Validation by Q-sort

The research team used a Q-sort nominal group process⁸ with mine personnel to rate each of the original list of 58 shuttle car activities in terms of the perceived likelihood of a costly consequence being associated with a performance error. Two researchers (both former shuttle car operators), a maintenance supervisor, a section supervisor, and a mine safety and skills trainer participated in the rating process.

The two-stage Q-sort procedure placed each activity into one of five categories based upon cost consequence: very low (VL), low (L), medium (M), high (H), and very high (VH) priority. The mechanics of Q-sort rely upon individual evaluation and group consensus. Appendix C provides details for the Q-sort procedure used at the study site.

During this Q-sort procedure, the list of 58 steps was further reduced to 48; 13 preshift activities, 3 idle-time activities, 9 tramming activities, 9 loading activities, 12 dumping activities, and 2 end-of-shift activities.

The summary information resulting from the initial rating session was reviewed with the entire group, and participants were asked to discuss the ratings given to each activity. At this time, participants also were given the opportunity to reevaluate their ratings and to change them on the basis of new information provided by the statistical summary and subsequent discussion. Following this second round of Q-sorting, rating data again were tabulated and summarized to determine the degree of consensus. This information was shared and again participants were asked to comment on their ratings. Participants were encouraged to comment on the nature of the potential costly consequences that might result from inadequate performance in each subtask.

During the discussion and rating process, some activities were seen as not applicable to the particular mining operation under study and were dropped from the list. In several cases, specific, closely related activities were clustered under more general descriptions. The complete list of 48 critical subtasks and the corresponding ratings developed through the Q-sort procedure are given in table 1. During the in-mine use of the behavioral observation checklist to observe and profile operational errors, this list of 48 subtasks was further refined to a total of 46.

⁷Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

⁸See reference 52 for an example of the use of Q-sort, as used to rank research and development projects for funding, given limited resources.

Table 1.—Shuttle car operation steps rated according to perceived cost consequences of inadequate performance

Task area	Does the operator—	Rating ¹
Preshift:		
1	Look for poor electrical connections at power center	L
2	Check location of cable snub to insure snub will keep cable out of path	H
3	Conduct walk around check of machine; examine fluid levels, reel compartment, tires and wheels; report missing bolts and covers.	M
4	Check parking brake and tram and brake pedals for proper function	H
5	Check panic bar with power on	M
6	Check pump start-up for proper cable take up	VH
7	Check boom by raising and lowering it	VL
8	Check operation of conveyor	VL
9	Check lights in both directions	VL
10	Ring bell before moving machine	VL
11	Turn on lights in direction of travel	H
12	Check brakes and steering while tramping	L
13	Tram slowly with first load near cable snub to check clearance	VH
Tramming:		
14	Tram appropriately for haul road conditions, rounding corners smoothly and keeping body inside compartment.	H
15	Watch for water hose and continuous miner and roof bolter cables while tramming	VH
16	Make certain that there is sufficient cable on reel to reach continuous miner	VH
17	Slow shuttle car down when approaching continuous miner	VH
18	Exercise care to prevent ramming continuous miner	VH
19	Stop behind continuous miner when boom is low	VH
20	Turn lights in opposite direction after reaching continuous miner	H
21	Watch for ventilation curtains	VH
22	Ring bell before moving machine ²	VL
Idle time activities:		
23	Clean operator's compartment	M
24	Check reel compartment for mud, damage, etc.	H
25	Check cable periodically for worn spots, damaged splices, etc.	H
Loading:		
26	Watch out for continuous miner cable and hoses when loading	VH
27	Position shuttle car under continuous miner boom while loading to prevent spillage	M
28	Signal continuous miner operator to reposition continuous miner boom as needed when loading ...	M
29	Jockey shuttle car in and out as continuous miner moves while cutting and loading	M
30	Pull load forward to prevent spillage off sides and end of shuttle car	VH
31	Prevent spillage of end of shuttle car boom when loading	H
32	Prevent load from piling too high and roofing or catching overhead cables	VH
33	Signal continuous miner operator when shuttle car is full using bell, lights, or caplight	M
34	Ring bell before leaving the continuous miner with a load ²	VL
Dumping:		
35	Raise boom (if height permits) when approaching feeder	M
36	Raise boom high enough to get good fall of coal when dumping	M
37	Pull shuttle car into feeder to prevent spillage when dumping	M
38	Use care to avoid ramming or banging feeder	VH
39	Set brake to prevent shuttle car from rolling back off feeder when dumping	M
40	Turn lights in opposite direction after reaching feeder	NR
41	Make certain that feeder is running before dumping coal ³	M
42	Dump coal at rate that complements feeder intake ³	M
43	Shut off conveyor before pulling away from feeder	H
44	Drop boom down after moving clear of feeder	M
45	Sound bell before leaving the feeder ²	VL
46	Swing shuttle car away from trailing cable when leaving feeder	VH
End of shift:		
47	Tram shuttle car to allowable parking area at end of shift	M
48	Cut wheels on shuttle car when parking to prevent roll away	VL

¹VH = very high; H = high; M = medium; L = low; VL = very low; NR = not rated.²Original text modified after Q-sort.³Items 41 and 42 were combined when rated.

These particular selected activities and associated ratings are specific to the particular mine site, equipment configuration, and work crew under study. For example, the Q-sort panel considered failure to consistently ring the shuttle car bell during tramping, loading and dumping operations (Activity 22, 34 and 45) very unlikely to result in a costly consequence. Members of the crew had worked together for some time, were experienced machine operators, and were cognizant of the habits and location of their fellow workers. As one rater suggested, changing these elements to "conditional" performance (e.g., ring bell when *uncertain* of other workers' location" - Activity 22; and make certain the area is clear of other workers and equipment before leaving the continuous miner with a load - Activity 34) could substantively modify the nominal group rating and, perhaps, be of more value during the work site observations. On the other hand, and even with an experienced crew, the face advanced fairly rapidly in this section and failure to check for sufficient cable (Activity 16) could easily and consistently result in a costly downtime event as rated by the Q-sort panel.

In summary, for this particular mine section:

1. Twenty-two operation activities were determined to be H to VH priority in terms of cost consequence.
2. Ten operation activities were determined to be L to VL priority in terms of cost consequence.
3. Information was obtained on possible types of downtime associated with each activity. For example, traveling faster than conditions permit could result in neck or back injury to the operator. However, a more likely downtime event might be damaged steering arms and wheel units.

The Q-sort procedure provided useful information, from several perspectives, about perceived cost consequences of operational errors. For example, of those activities rated VH and H, most concerned easily definable functions such as cable management (10 items), preventing damage to the continuous miner (3 items), spillage (3 items), and tramping at an appropriate speed. Specific penalties for noncompliance with activity descriptions rated L to VL were much more variable and difficult to quantify. In practice, the Q-sort method is viewed as a useful technique for tailoring general task analyses to fit specific mine environments and operating procedures using knowledge obtained from a veteran work force. Consensus is accomplished through the sharing of information among supervisors, machine operators, safety, and maintenance personnel. The specific Q-sort procedure was designed by the research team to ascertain information and obtain consensus on subtask importance prior to the worksite observations. The procedure, in retrospect, was a training intervention. The benefit might have been measured (although not in this study) by the *shift* of the Q-sort rankings by the

panel based on knowledge offered to the group by individual participants. In short, the Q-sort procedure helped to define the difference between the rather pure and sterile job procedures (e.g., SOPs, and JSAs) and practice. This bridge was constructed through the interchange among experienced miners guided by the design of the nominal group technique.

Time Study Data

To validate the task analysis and to test behavioral observation techniques, members of the research team conducted time-motion studies of shuttle car operations at the cooperating mine site. Three regular and three incidental operators in one mining section were observed over two shifts on two different days to estimate the typical rates and variabilities of normal room-and-pillar operations. Two observers were used. One was located at the continuous miner recorded loading times. A second observer, at the belt tailpiece, collected time data at the dumping point. These data are summarized in table 2.

Table 2.—Time study data comparing load and dump times among subject shuttle car operators¹

Operators	Loading			Dumping		
	N	Mean	SD	N	Mean	SD
Regular:						
A	103	1.26	0.438	66	0.80	0.145
B	145	1.17	.511	128	.70	.105
C	116	1.14	.345	116	.79	.209
Total or weighted av	364	1.19	NAp	310	.75	NAp
Incidental:						
D	20	1.20	.309	12	.76	.219
E	54	1.39	.506	66	.74	.104
F	52	1.10	.243	58	.90	.296
Total or weighted av	126	1.24	NAp	136	.81	NAp
All: Total or weighted av	490	1.20	NAp	446	.77	NAp
av average.	NAp		Not applicable.			
N Number.	SD		Standard deviation.			

¹Times are average number of minutes per activity.

The time study data show significant intrasubject variability for loading and dumping; therefore, standard time study techniques for analyzing shuttle car operation were determined to be of little utility to characterize or to differentiate performance among operators. It is worth noting that all of the regular operators had about the same level of experience in shuttle car operation.

Although not shown explicitly in the composite time study data of table 2, it should be emphasized that shuttle car operator proficiency is difficult to isolate through the timing of duty cycle elements. It was hypothesized that the overall proficiency of the shuttle car operator (e.g., ability

to properly position the machine, knowing when to run the conveyor, and watching the miner boom position when loading) could be related to these time elements. It was obvious during the data collection, however, that other factors account for significant amounts of variability in load time. Examples include:

1. Location of cut in the cut sequence. When a cut is being loaded "straight on" in an entry, loading is easier and load times are less than when a first or second cut is taken when starting a crosscut (due to more equipment maneuvering and shortened lines of sight).

2. Payload variability. Although, in general, shuttle car payload varies less than 0.5 st from one car to the next, the last car in the cut, known as the clean-up car, might be lightly loaded, resulting in unusually low load times. Furthermore, for this clean-up car, load time can be disproportionate to payload, since frequently the miner load rate is lower due to greater in-place maneuvering and due to smaller and more widely distributed piles of precut coal.

3. Proficiency of the miner operator and position in the cut sequence. It is characteristic for a good miner operator to cut coal while waiting for a shuttle car to return for another load, thereby lowering load time. If the miner operator does not continue or resume cutting after loading out a shuttle car, coal must be cut and loaded at the same time, thus increasing load time. Even if the miner operator consistently cuts coal between shuttle car arrivals, the time available for preload preparations varies with the miner's position in the cut sequence. When mining early in the cut sequence in an entry near the section feeder, for example, a returning shuttle car might already be available for loading (empty at the miner change out point) when the other shuttle car leaves the miner in a loaded state.

Another hypothesis of the study was that shuttle car discharge times could be linked to shuttle car operator proficiency. It was theorized that a proficient operator skillfully positions the car deeply into the feeder, permitting fast discharge; and then backs the car off the feeder, completely discharging its load into the inby end of the feeder. Unfortunately, there are other confounding factors that independently affect dump time, which, although recently investigated and reported on elsewhere (53-54), may be summarized as follows:

1. Payload variability. Obviously, dump time is proportional to the size of the load to be discharged. Dump time variability is especially evident due to clean-up requirements.

2. Feeder bin capacity, load state, and feeder discharge rate. With large bin capacity, an empty hopper upon inception of dump, and a high feeder discharge rate, the

shuttle car operator can frequently dump nearly the entire load without interrupting the chain conveyor. If, however, the feeder has retained a portion of the load from the previously dumped shuttle car or if the feeder discharge rate is lowered, as could be done to mitigate downstream belt spillage, the dump time may be increased, irrespective of operator proficiency.

3. Feeder position. If the feeder is positioned too close to the crosscut, the shuttle car operator cannot dump at the maximum rate due to a diminished effective feeder bin capacity and because of the reduced clearance between the discharge boom and the feeder's spill plates. This situation can be worsened in miner sections that utilize two-way and three-way dumps.

After interpretation of these time study data and recognizing the inherent difficulties in factoring out variability exclusive of operator proficiency, differences in load and dump time were rejected for assessing machine operator performance. Although mean load and dump times were higher for some operators than for others and the data suggested that regular operators outperformed incidental operators, no firm inferences could be drawn.

This time study experience, however, confirmed the operation steps that had been identified earlier through Q-sort and facilitated the ensuing worksite observations. More importantly, it offered data to weigh the relative advantage of using behavioral observations to measure performance as opposed to the more classical or traditional use of time and motion data to assess crew member (or system) performance. The time study data was, in effect, discarded by the study team as being relatively insensitive to conditions and important behaviors that have a marked impact on quality output (safe and proficient performance) as opposed to the behavioral profile developed via the Q-sort procedure.

WORK SITE OBSERVATIONS

Research Design

The completed task analysis guided the development of evaluation tools to measure performance and to estimate proficiency. Proficiency with complex tasks in dynamic work environments is best estimated using a sampling procedure involving a series of observations and evaluations over an extended period of time. Each observation is a measuring occasion, yielding data representing the observer's judgments on the quality of the specific activities or task performances being observed. The number of observations and the time interval over which these data are collected need to be sufficient for the variability in worker performance to be sampled adequately.

The research design used in this study sought to minimize biases stemming from the use of *ad hoc* groups by making use of archival data that showed no significant differences in sample characteristics (age, years of service, and amount of training) among participants in each study group. The use of human observers as the agents of measurement is sometimes faulted on grounds of subjectivity and unreliability. However, a person is often the best and sometime the *only* instrument capable of appraising the success or appropriateness of human behaviors in complex task and skill domains. A variety of techniques proved useful in improving data obtained from the two independent observers in this study. These included: (1) carefully defining and building consensus about what is to be observed and what constitutes examples of poor or inadequate performance; (2) minimizing the number of discriminations that the observer is being asked to make (e.g., by using a dichotomous rating scale); (3) implementing unthreatening and unobtrusive data collection procedures; and (4) pooling data from multiple observers when developing proficiency estimates. Finally, *post hoc* statistical analysis proved useful in estimating the degree to which interpersonal and intrapersonal variabilities in observers influence the estimation process.

Because of the restrictive conditions of the underground mining environment (55), and because of the desire for data collection to be minimally obtrusive, and thus unthreatening, experienced and trained observers were used. Both observers were able to recognize the behaviors to be observed, were able to use the observer system with ease, and were able to make observations in accordance with some standard of criteria, as recommended by Spool (56) in his study of training programs for behavioral observers. Selection bias, including what is known as volunteer bias, could not be controlled in this study, but even if present, was considered inconsequential to the accomplishment of project goals.

Behavioral Observation Checklist

A behavioral observation checklist for shuttle car operators based on the activities listed in table 1 was designed for underground use by the research team. One version of this form is shown in figure 2. The checklist was divided into sections corresponding to clusters of activities related to particular task areas. An additional section was used to identify the observer, the machine operator, the work crew, the equipment in use, and other contextual factors of peripheral interest. The form provides five data boxes beneath each activity description for multiple observations of the same individual recorded over a time interval. Similar forms later were used successfully by the section supervisor.

Visual Observations

Visual observations of three regular and three incidental shuttle car operators were recorded by two members of the research team during several shifts over a period of 3 weeks. The observers repeatedly evaluated each operator's performance in each activity and task area defined by the task analysis and Q-sort process. An event sampling method was used, with observations of discrete events recorded at different locations, which, it was assumed, had equal likelihood of occurrence among subjects. Dichotomous observational data were recorded using a behavioral observation checklist similar to that shown in figure 2. A "+" was indicated if the appropriate behavior was observed. A "-" indicated a performance error, omission, or inadequacy. Observers were free to move through the section to permit viewing of all shuttle car operation steps. Each observer watched each operator performing each routine activity at least 10 times over the observation period. Preshift and end-of-shift activities were evaluated approximately five times for each operator, as data collection opportunities were presented. Notes were kept on operator performance, as well as on mining conditions and other factors that might affect shuttle car operation.

Data Analysis

After a few shifts of observation, differences were noted in levels of performance among the shuttle car operators. As a result, evaluators were able to rank all regular and incidental shuttle car operators according to proficiency profiles based on the visual observation data. Figure 3 illustrates the differences in performance between regular and incidental operators for selected groups of shuttle car operation steps, aggregated by task type and cost consequence.

This figure clearly shows that observers were able to visually discriminate differences in levels of task (grouping of subtask) performance among both regular and incidental operators. Although the small number of operators observed (three regular and three incidental) did not warrant statistical treatment of the data, the trends are clear. Operator proficiencies differed substantively as a function of the type of task being performed, the type of operator performing the task, and as a function of the perceived criticality (i.e., likelihood of costly consequences associated with poor performance) of particular job activities.

Regarding the *type of task*, the observational data explicitly indicates that both incidental and regular operators were more proficient in some tasks than others. This might be explained by workers paying more attention to those tasks that are of higher perceived cost consequence,

MINE: _____ SECTION: _____ FOREMAN: _____	SC OPERATOR: _____ DATE: _____ SHIFT: _____ OBSERVER: _____ SC: _____
---	---

PRESHIFT – Does the operator:

1. Look for poor electrical connections at power center.
 Observations: ☐ ☐ ☐ ☐ ☐
2. Check location of cable snub to insure snub will keep cable out of path.
 Observations: ☐ ☐ ☐ ☐ ☐
3. Conduct walk around check of machine; examine fluid levels, reel compartment, tires and wheels; report missing bolts and covers.
 Observations: ☐ ☐ ☐ ☐ ☐
4. Check parking brake and tram and brake pedals for proper function.
 Observations: ☐ ☐ ☐ ☐ ☐
5. Check panic bar with power on.
 Observations: ☐ ☐ ☐ ☐ ☐
6. Check pump startup for proper cable takeup.
 Observations: ☐ ☐ ☐ ☐ ☐
7. Check boom by raising and lowering it.
 Observations: ☐ ☐ ☐ ☐ ☐
8. Check operation of conveyor.
 Observations: ☐ ☐ ☐ ☐ ☐
9. Check lights in both directions.
 Observations: ☐ ☐ ☐ ☐ ☐
10. Ring bell before moving machine.
 Observations: ☐ ☐ ☐ ☐ ☐
11. Turn on lights in direction of travel.
 Observations: ☐ ☐ ☐ ☐ ☐
12. Check brakes and steering while tramping.
 Observations: ☐ ☐ ☐ ☐ ☐
13. Tram slowly with first load near cable snub to check clearance.
 Observations: ☐ ☐ ☐ ☐ ☐

TRAMMING – Does the operator:

14. Tram appropriately for haul road conditions, rounding corners smoothly and keeping body inside compartment.
 Observations: ☐ ☐ ☐ ☐ ☐
15. Watch for water hose and CM and roof bolter cables while tramping.
 Observations: ☐ ☐ ☐ ☐ ☐
16. Make certain that there is sufficient cable on reel to reach the continuous miner.
 Observations: ☐ ☐ ☐ ☐ ☐
17. Slow shuttle car down when approaching continuous miner.
 Observations: ☐ ☐ ☐ ☐ ☐
18. Exercise care to prevent ramming CM.
 Observations: ☐ ☐ ☐ ☐ ☐
19. Stop behind CM when boom is low.
 Observations: ☐ ☐ ☐ ☐ ☐
20. Turn lights in opposite direction after reaching CM.
 Observations: ☐ ☐ ☐ ☐ ☐
21. Watch for ventilation curtains.
 Observations: ☐ ☐ ☐ ☐ ☐
- *22. Ring bell when uncertain of other workers' location.
 Observations: ☐ ☐ ☐ ☐ ☐

IDLE TIME ACTIVITIES – Does the operator:

23. Clean operator's compartment.
 Observations: ☐ ☐ ☐ ☐ ☐
24. Check reel compartment for mud, damage, etc.
 Observations: ☐ ☐ ☐ ☐ ☐
25. Check cable periodically for worn spots, damaged splices, etc.
 Observations: ☐ ☐ ☐ ☐ ☐

Figure 2.—The behavioral observation checklist.

LOADING – Does the operator:

26. Watch out for continuous miner cable and hoses when loading.

Observations: ☐ ☐ ☐ ☐ ☐

27. Position shuttle car under continuous miner boom while loading to prevent spillage.

Observations: ☐ ☐ ☐ ☐ ☐

28. Signal CM operator to reposition CM boom as needed when loading.

Observations: ☐ ☐ ☐ ☐ ☐

29. Jockey shuttle car in and out as CM moves while cutting and loading.

Observations: ☐ ☐ ☐ ☐ ☐

30. Pull load forward to prevent spillage off sides and end of shuttle car.

Observations: ☐ ☐ ☐ ☐ ☐

31. Prevent spillage of end of SC boom when loading.

Observations: ☐ ☐ ☐ ☐ ☐

32. Prevent load from piling too high and "roofing" or catching overhead cables.

Observations: ☐ ☐ ☐ ☐ ☐

33. Signal CM operator when SC is full using bell, lights or caplight.

Observations: ☐ ☐ ☐ ☐ ☐

- *34. Make certain that area is clear of other workers and equipment before leaving the CM with a load.

Observations: ☐ ☐ ☐ ☐ ☐**END-OF-SHIFT – Does the operator:**

47. Tram shuttle car to an allowable parking area at end-of-shift.

Observations: ☐ ☐ ☐ ☐ ☐

48. Cut the wheels on shuttle car when parking to prevent roll away.

Observations: ☐ ☐ ☐ ☐ ☐**DUMPING – Does the operator:**

35. Raise boom (if height permits) when approaching the feeder.

Observations: ☐ ☐ ☐ ☐ ☐

36. Raise boom high enough to get a good fall of coal when dumping.

Observations: ☐ ☐ ☐ ☐ ☐

37. Pull shuttle car into feeder to prevent spillage when dumping.

Observations: ☐ ☐ ☐ ☐ ☐

38. Use care to avoid ramming or banging feeder.

Observations: ☐ ☐ ☐ ☐ ☐

39. Set brake to prevent SC from rolling back off feeder when dumping.

Observations: ☐ ☐ ☐ ☐ ☐

- ***40. Turn lights in opposite direction after reaching feeder.

Observations: ☐ ☐ ☐ ☐ ☐

- **41. Make certain that feeder is running before dumping coal.

Observations: ☐ ☐ ☐ ☐ ☐

- **42. Dump coal at a rate that complements feeder intake.

Observations: ☐ ☐ ☐ ☐ ☐

43. Shut off conveyor before pulling away from feeder.

Observations: ☐ ☐ ☐ ☐ ☐

44. Drop boom down after moving clear of feeder.

Observations: ☐ ☐ ☐ ☐ ☐

- *45. Make certain that area is clear of other workers and equipment before leaving feeder.

Observations: ☐ ☐ ☐ ☐ ☐

46. Swing shuttle car away from trailing cable when leaving feeder.

Observations: ☐ ☐ ☐ ☐ ☐

* Original text modified after Q-Sort.

** These items were combined on the original form.

*** This item was not included on the original form.

Figure 2.—The behavioral observation checklist—Continued.

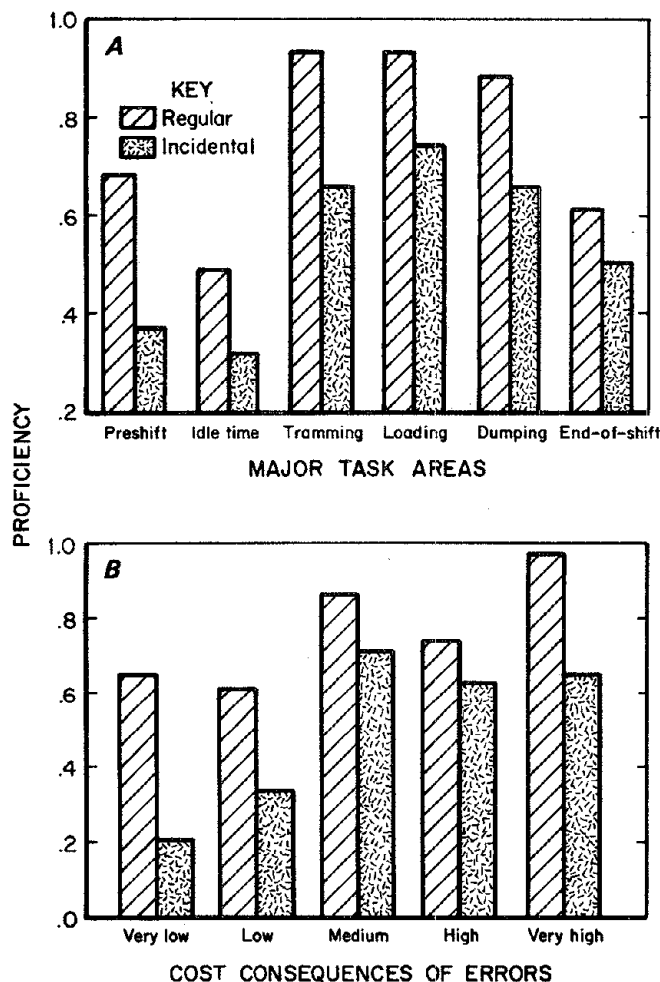


Figure 3.—Regular and incidental operator proficiency.

some of the tasks being more routine (e.g., tramming, loading, and dumping) and directly tied to crew output than other tasks (idle time, preshift, and end of shift) activities, or by the better design, supervision, and follow-up of some tasks compared to others.

Regarding the *type of operator*, for each of the major task areas, regular operators consistently outperformed the incidentals. As mentioned above, the small sample size and the expected high variability, for small sample sizes within each operator type, did not permit statistical treatment of the data. Replication of the study would need to include larger sample sizes for statistical treatment.

In sum, proficiency profiles were the highest for both incidental and regular operators among those tasks (aggregates of subtasks involving tramming, loading, and dumping) often associated with bottom line, traditional measures of crew output. Of note, performance profiles, for both the regular and incidental operators, paralleled the subtask ranking from the nominal-group, Q-sort procedure. However, the adherence of incidental operators to

task procedures was substantively below the regular operators when analyzed by task or consequence. Operator proficiency was calculated by:

$$\text{Proficiency} = \frac{\text{number of correct behaviors observed}}{\text{total number of behaviors observed}}$$

In this study, sample size was not critical to the outcome of the project, although it is recognized that there is a method for determining the number of random observations required for a given absolute accuracy when making a multiple activity work sampling study (36, 47, 57-58). The large number of subtasks observed in this study, the varying observed percentages of activities, and the limited time for observation in a production setting made compromises in study design necessary.

Reliability of Observational Data

The use of two observers, who independently observed operators performing job-related activities over a period of time, permitted the statistical study of the internal consistency and interrater reliability of proficiency estimates in each of the major task areas involved in shuttle car operation. Proficiency estimates were calculated by pooling both observers' judgments for each machine operator in each activity and averaging these data over each task area. Task areas composed of independent activities were treated as "scales" comprised of "items," and Cronbach's Alpha reliability coefficients (59) were computed to estimate the degree of internal consistency among the "items" forming each "scale." Alpha estimates between 0.800 and 0.999 for those task areas spanning a sufficient number of discrete activities to permit analysis indicated a very high degree of internal consistency in observer ratings of machine operator proficiencies using the WCPM methodology, as shown in table 3. These statistics indicated that if an operator is observed performing some of the activities comprising a task area consistently and well, then it is likely that operator also performs the other activities within that task area equally well, and *vice versa*.

A research design that provides data recorded by multiple observers concerning a group of closely related but independently sampled activities lends itself to a split-plot analysis of variance (ANOVA) involving effects for activities, machine operators, and the observers rating the operators. Such designs are tailor-made for the application of generalizability theory (59) to determine appropriate estimates of the dependability of the data, given various assumptions about the nature of the sampling design and the intended use of proficiency information. Table 3 reports dependability information for machine operator proficiency estimates in each task area under three generalizability conditions: (1) activities are considered randomly sampled

Table 3.—The dependability of proficiency estimates based on behavioral observation data

Scale	Number of items	Cronbach's alpha	Dependability estimates		
			Random tasks, random operators	Fixed tasks, random operators	Random tasks, fixed operators
Preshift operations	13	0.938	0.932	0.996	0.931
Tramming operations	9	.938	.940	.998	.938
Idle time activities	3	.530	.521	.966	.530
Loading operations	9	.811	.783	.965	.811
Dumping operations	¹ 10	.870	.864	.998	.860
End-of-shift activities	2	(²)	(²)	(²)	(²)
Overall operator proficiency . .	46	.976	.975	.998	.975

¹ Data based on original checklist.

² Too few items to compute coefficient; however, raters were in almost perfect agreement.

from a universe of similar activities comprising a particular task area, and observers are sampled from a population of similar observers; (2) the list of activities is fixed and considered to define collectively the task area being studied, while again observers are sampled randomly; and (3) the activities are sampled randomly but only the evaluations of this particular group of observers are of interest. Were the data organized into replication sets (e.g., first quarter, second quarter, etc.), a fourth dependability measure for fixed activities and fixed observers could then be computed. For each set of generalizability conditions, the set of "machine operators" is considered to be a random effect, consistent with the recommended statistical treatment (60-61).

For most purposes related to the WCPM, generalizability conditions (1) and (2) above are probably the most appropriate to consider. The data in table 3 indicate that WCPM proficiency estimates provide very dependable measures for generalizability. For example, a particular machine operator's estimated tramming proficiency would have been just about the same had other activities (similar to those employed above) been used or had other observers (similar to the researchers who participated in this study) been involved in the performance observing and rating process.

INITIAL STUDIES OF COST LINKAGES

Thus far, the utility of the behavioral observation methodology to profile and describe variability in performance among shuttle car operators has been demonstrated. For example, the operators observed were conscientious about proper cable management, travel speed, attentiveness to haul road conditions, and avoidance of spillage when loading or dumping. One operator, in particular, performed most activities involved in shuttle car operation more consistently and with fewer errors than his peers. This individual could be identified as an exemplary operator. In contrast, the incidental operators consistently

appeared less proficient (i.e., greater variability in the adherence to task-subtask procedures).

The objective of the initial cost linkage studies was to examine relationships among machine operator proficiency profiles and a variety of logical, dependent variables that can be associated with operator error. Accepting the earlier premise (10, 24, 26; see appendix B) that production and injury data have limited utility for decisions regarding the selection of performance improvement strategies or the allocation of treatment resources, the data were discounted. Further support for the abandonment of any statistically significant cost linkage between production and injury data and behavioral profiles was the problem inherent in comparing a three-week "snapshot" to a year's performance.

Mechanical and Production Downtime Rates

Mechanical and production downtime data for shuttle cars were obtained for the mine site where the behavioral observations were conducted. Information for the one-year period which encompassed the three-week observation period was analyzed.

The mechanical and production downtime data were entered into a database on a Digital Equipment VAX minicomputer using POISE data management software. For the year, over 800 separate downtime incidents were isolated. Only data for coal production shifts were entered. Data for events associated with idle and maintenance shifts were excluded. The reported downtime event information included shift number, shuttle car number, date of the occurrence, downtime delay code (a code number assigned by the company to identify the nature of the delay), number of minutes in mechanical and production delay, and descriptions or remarks about each delay. The downtime data were sorted and grouped according to shuttle car number and delay code. The number of delays for each code category for each shuttle car was tabulated. At the same time, total production and

mechanical downtime incurred for each delay type was also calculated.

The delays reported were compared with the 46 shuttle car operation steps to determine which steps, if not performed properly, might result in each reported delay. For each delay, the steps that could possibly be linked to the delay were listed.

Table 4 gives the results of the downtime analysis for one section operating two shuttle cars per shift over a 12-month period. Twenty-nine sources of downtime are listed. These are categorized into four groups: electrical,

hydraulic, mechanical, and miscellaneous. Many downtime sources are relatively rare and not reasonably attributable to operator errors, such as the single instance of pump motor failure. Others, such as steering arms, and spooling device or cable problems, could logically be related to operator error or lack of proficiency over a period of time, leading to eventual mechanical failure. Note that cable problems accounted for almost one-half of the over \$100,000 lost due to shuttle car downtime on this one section.

Table 4.—Shuttle car downtime analysis¹

Category	Number of downtime events ²			Production downtime, min			Cost, ³ combined shifts
	Morning shift	Afternoon shift	Combined shifts	Morning shift	Afternoon shift	Combined shifts	
Electrical:							
Breaker	1	4	5	50	52	102	\$1,224
Cable	121	98	219	2,228	1,695	3,923	47,076
Contactors nips	3	2	5	45	27	72	864
Lights	10	2	12	110	10	120	1,440
Overload relay	6	0	6	150	0	150	1,800
Pump motor	0	1	1	0	60	60	720
Reverse tram switch	2	3	5	25	30	55	660
Miscellaneous cable	2	0	2	20	0	20	240
Miscellaneous electrical	6	4	10	229	115	344	4,128
Hydraulic:							
Hoses	3	2	5	40	40	80	960
Jacks	1	0	1	20	0	20	240
Master cylinder	1	0	1	8	0	8	96
Pump	0	2	2	0	140	140	1,680
Steering jack	0	3	3	0	63	63	756
Steering valve	3	2	5	52	27	79	948
Miscellaneous hydraulic	13	12	25	254	181	435	5,220
Mechanical:							
Brake disc and head	10	3	13	270	83	353	4,236
Cable reel	0	1	1	0	35	35	420
Conveyor chain	6	1	7	235	5	240	2,880
Drive flange yoke	1	0	1	25	0	25	300
Drive shaft and sprocket	0	1	1	0	32	32	384
Reel chain	2	3	5	17	57	74	888
Spooling device	21	20	41	410	397	807	9,684
Upper steering arm	0	2	2	0	25	25	300
Miscellaneous mechanical	26	20	46	643	342	985	11,820
Miscellaneous:							
Fill with oil	1	6	7	10	50	60	720
Service	2	2	4	72	25	97	1,164
Tires-flats	1	0	1	5	0	5	60
Welding	3	3	6	30	45	75	900
Total	245	197	442	4,948	3,536	8,484	\$101,808

¹One section operating two shuttle cars per shift over a 12-month period.

²Actual number of downtime events recorded in company records.

³Estimated cost at \$12 per minute of production downtime.

Unfortunately, the analysis of the shuttle car downtime data routinely collected by the mining company and provided to the research team proved inconclusive. The downtime data for the mine section *did* reveal considerable variability between shifts and among shuttle cars in terms of the frequency of particular kinds of incidents and the magnitude of the associated productivity losses. (It is of interest to note that the particular shuttle car most frequently operated by the individual perceived as the exemplar had the least number of reported downtime incidents during his shift.) Refer to appendix D for specific comments concerning the collection and recording of downtime events. Also included in appendix D are other possible explanations for the lack of a conclusive relationship between shuttle car downtime and the performance results obtained by the observational techniques employed in the WCPM methodology.

Face Production Simulation: Linking Production Estimates to Common Operating Parameters

Discussion thus far has been limited to the use of observational techniques to establish performance baselines, to measure learning outcomes, and to study cost linkages between job competencies and measures of consequence.

The research reported here summarizes an investigation into the impacts of variability of shuttle car operator performance on estimates of production. This variability was expressed in terms of measurable operating parameters inherent in the duty cycle of a continuous mining development section (62). This study recognized that production can be impacted by variability in such areas as payload, load time, dump time, and tram rate, and that observable data and probability distributions for these data can be linked to operator proficiency. Unfortunately, the cost consequences resulting from deviations from optimum operation frequently are subtle, of unpredictable magnitude, and can be confounded by other variables (e.g., breakdown characteristics and empirical distributions of individual cycle time elements and operation rates). The computer simulation that was performed as a case study permitted investigation into the effects that controllable operating parameters can have on production.

Test Design

CONSIM (63), a discrete, event-oriented simulation program for analyzing face operations in continuous mining systems, was used to begin to understand these interrelationships. The major events in CONSIM include cutting and loading, hauling, roof bolting, and equipment breakdowns. Input data are relatively simple and essentially include the dimensions of the section (e.g., number of headings; number of cuts in the sequence; dimensions

of pillars, headings, and breakthroughs; cut depth; and change out distance), and the operational characteristics of the face equipment (e.g., length; tram rates of miner and bolter; breakdown data; empirical distributions for shuttle car payload, load rate, haul rate, discharge rate; and in-place constants). Several of these operating parameters can be viewed as being linked to operator proficiency. For example, the exemplary shuttle car operator consistently will achieve optimum payload, will interact with the miner operator to maintain a high load rate, and will minimize time at the discharge point. CONSIM permits rapid investigation into the effects of changes in these and other operating parameters on production.

Figure 4 shows the hypothetical, idealized, yet realistic, section layout used for the analyses. Pertinent input data for the base case not conveyed in figure 4 are as follows:

Shift production time	360 min
Coal density	0.042 st/cu ft
Continuous miner tram rate ⁹	0.015 min/ft
Roof bolter tram rate	0.010 min/ft
Switch-in time per haul cycle ¹⁰	0.15 min
Switch-out time per haul cycle ¹¹	0.15 min
Miner in-place constant ¹²	4.0 min
Bolter in-place constant	4.0 min
Length of belt to be advanced	125 ft
Miner load rate	0.20 min/st
Shuttle car payload	7.2 st
Tram rate from miner to change point	0.0030 min/ft
Tram rate from change point to dump	0.0028 min/ft
Tram rate from dump to change point	0.0027 min/ft
Tram rate from change point to miner	0.0026 min/ft
Discharge time	0.56 min
Roof bolter cycle time	32 min
Mining height	6 ft
Breakdown characteristics	Breakdowns disallowed

An 8 by 8 test matrix was constructed, with payload varied from base case conditions (7.20 st) to 35 pct under base case (4.68 st) and discharge time varied from base case conditions (0.56 min) to 35 pct over base case (0.756 min), both in 5 pct increments. The objective was to test the effects of the changes in these operating characteristics on such measures as production rate, time to load the cut sequence, load time percentage, percentage of time waiting for a shuttle car, and st per shuttle car mile. To remove variability both within and among sets of runs, all tram rates, payloads, and load rates were treated as constants, and no breakdowns were permitted to occur.

⁹CONSIM requires input of tram rates in units of min/ft.

¹⁰Time required for an empty shuttle car to provide clearance for a loaded car by tramping into an entry at the change out point.

¹¹Time required by the shuttle car to return to the haulage road after switch-in.

¹²Time required for any function other than production (e.g., gas check, hang brattice, check sprays, and prepare miner to load).

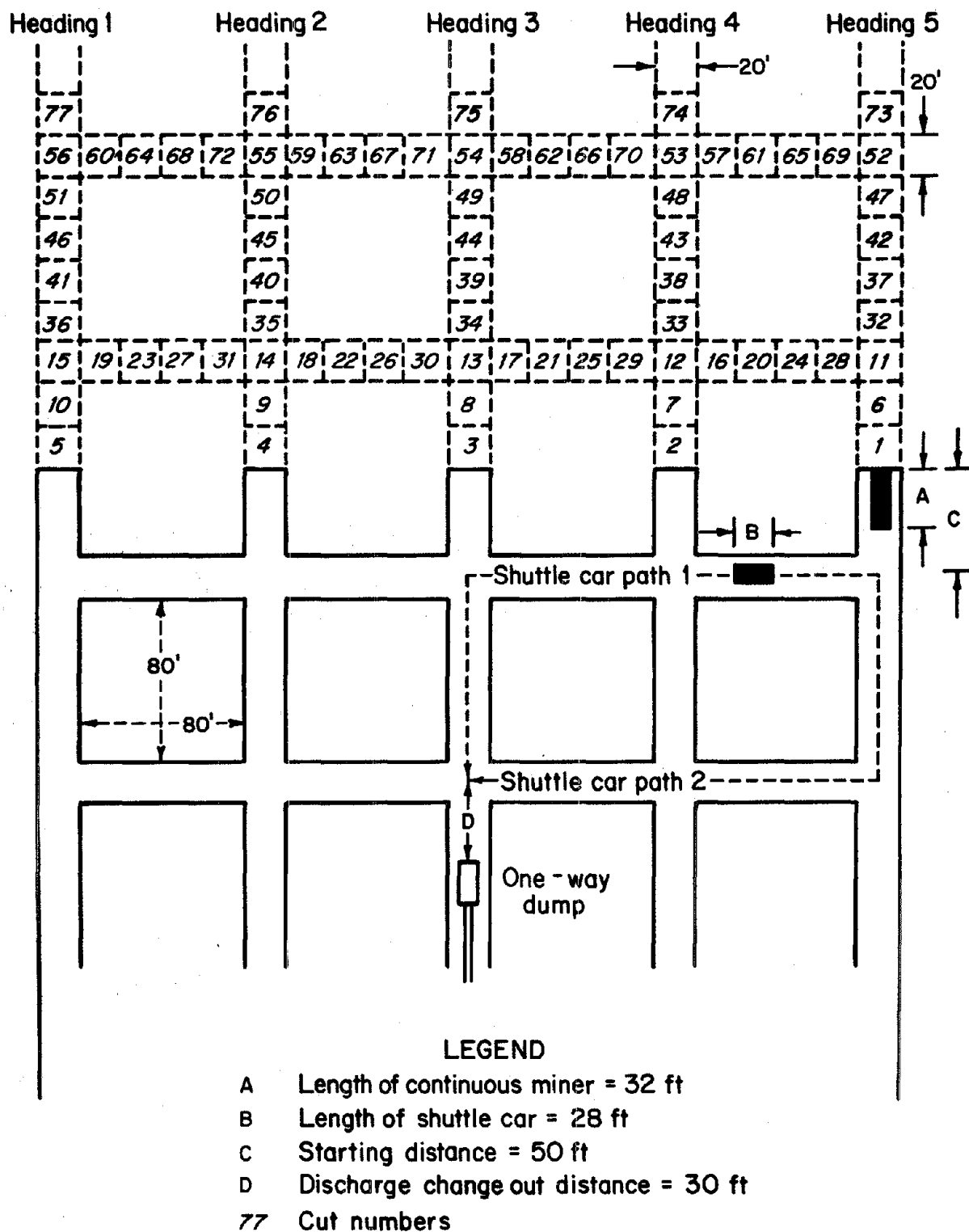


Figure 4.—Hypothetical, idealized section layout, showing cut sequencing and some system variables (after Topuz, Nasuf, and Ramachandran (63) p. 32).

Representative Test Results

Figure 5 shows the interrelationships among discharge time increase, payload decrement, and simulated production rate. As one would expect, production decreases with a decrease in the effective payload. At the base case conditions, for example, the simulated production is 2.61 st/min; at a 35 pct payload reduction, the simulated production is 2.30 st/min. This represents an 11.9 pct production decrement. Interestingly, simulated production actually increases slightly (but not significantly) with a 5 pct reduction in payload from base case conditions (7.20 to 6.84 st) before predictably decreasing as payload is incrementally reduced between runs. This occurs because of the complex interactions among load time, payload, and tram rates at these near-optimum payloads, which are best analyzed by mathematical simulation.¹³ A further potential complication is the variability in the clean-up car payload in each of the 77 cuts of the sequence between successive sets of runs.

Figure 5 also shows that a 35 pct increase in discharge time over the base case conditions results in only a 0.55 pct production decrement. These results indicate that, for the hypothetical section used in this study, maintaining a good payload is much more important than minimizing dump time. This example shows how production analyses can be used to rank candidate subtasks for performance improvement attempts and to help carry out cost-benefit analyses.

Figure 6 shows the effect of tram rate increases on the simulated production rate. For each of the eight simulation runs, velocity on each of the four shuttle car haul components was increased in increments of 0.0001 min/ft, which, for example, amounts to an increase of 11.5 ft/min (0.131 mph) between tram rates of 0.003 min/ft and 0.0029 min/ft. An increase in tram rate of 0.0007 min/ft in each of the four haul segments [0.0023 from 0.003, 0.0021 from 0.0028, 0.002 from 0.0027, and 0.0019 from 0.0026 (see previous input data), amounting to increases of 23.3, 25, 25.9, and 26.9 pct, respectively] results in only a 0.136 pct increase in simulated production rate, or 0.036 st/min. In one shift (assuming 360 min of production time), this amounts only to about 13 st. It is probable, then, that the cost consequences of accidents and downtime as a result of overspeed on haul roads greatly exceed the economic benefit of increasing tram speed over base case conditions. In this case, a simulated tram rate increase of approximately 25 pct over base case conditions resulted in a production increase equivalent to less than

¹³Results in appendix E indicate that for payloads above about 7 st, there are no further significant production gains, even if it can be assumed that discharge time can be held constant at these higher payloads.

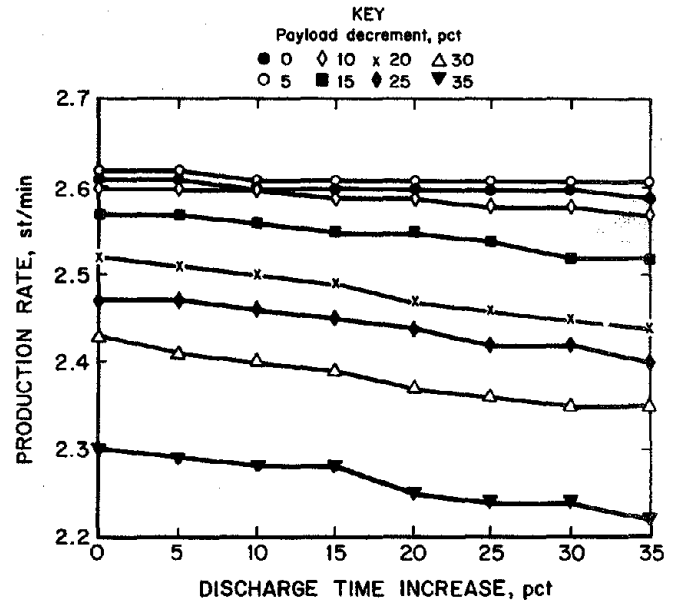


Figure 5.—Simulation results; interrelationships among payload decrement, discharge time increase, and production rate.

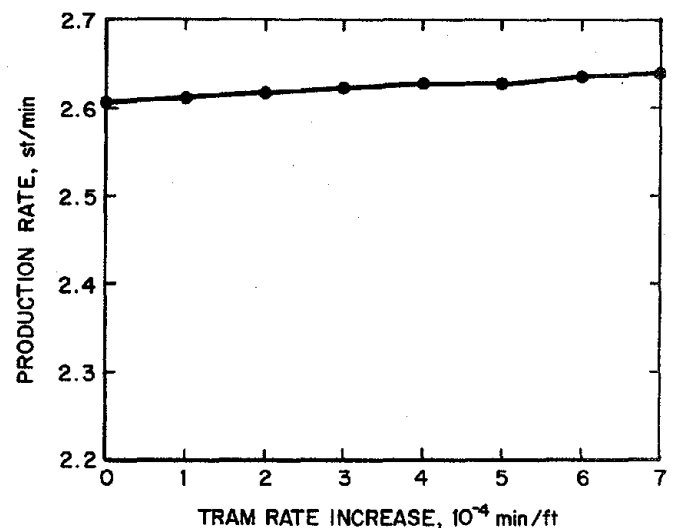


Figure 6.—Simulation results; effect of tram speed increase on production rate; 7.20 st payload, 0.56 min discharge time.

two shuttle car loads per shift. These results, as well as others included in appendix E, demonstrate the value of production simulation when performing equipment selection and sizing (63-64). It is recognized, however, that many operating parameters are not independent, as had to be assumed for this application of CONSIM. For example, it is clear that discharge time varies with payload, which, if incorporated into this simulation, would have further diminished the effect of dump time increases on production for progressively lower payload conditions. Furthermore, the results of these simulations point to the

interaction between operating parameters and the haul cycle components themselves, especially load time and shuttle car wait time.

Use of face production simulations, such as CONSIM, in conjunction with a behavioral observation program, can help identify and rank cycle elements for implementation of intervention strategies. This, in turn, can help human

resource developers better target groups of tasks and sub-tasks activities as candidates for improvement. The net result is the acquisition of an ability to offer more specific guidelines for human resource development (HRD) at the mine site. These guidelines would be based on empirical evidence and outcome measures.

SUMMARY

Traditional methods of measuring training effectiveness and evaluating miner performance, such as injury data, production quality, or productivity measures, are too broad or too generic to be useful in long-term performance improvement programs. Robertson (65), in his discussion of injury control strategies, states that "A basic cultural theme in the United States, perhaps as widely shared as any in a diverse society, is that sufficient education will resolve almost any problem....These programs would attempt to change behaviors that contribute to injuries...but the ultimate issue is whether the relevant behavior is changed and if the change is sufficient and sustained enough to reduce injuries. Success is claimed more often than demonstrated, and failure is experienced more often than admitted."

The WCPM offers an improved method of measuring training effectiveness and evaluating crew member performance within the practical confines of the work system. It relies on the cost-benefit assessment of operator skill based on observing those activities under the direct control of the equipment operator that are more reliable indicators of proficiency and, ultimately, organizational effectiveness.

With the cooperation and support of a medium-sized coal company and beginning with a thorough job analysis for shuttle car operation, a subset of critical tasks was identified and validated by a Q-sort procedure. These critical activities were associated with resultant errors deemed to have high likelihoods of injury, downtime, or otherwise costly consequences. Using a newly devised behavioral observation checklist for shuttle car operation, visual observations of the performance of these tasks were recorded, as judged against standards of performance determined cooperatively by mine management, trainers, equipment operators, and the USBM research team. Attempts to correlate proficiency ratings with downtime and production statistics proved to be largely inconclusive. Operator proficiencies differed substantively as a function of the type of task being performed, the type of operator performing the task, and as a function of the perceived criticality (i.e., likelihood of costly consequences associated with poor performance) of particular job activities. A linkage between performance errors and cost consequences was evidenced, but not proven.

In a related follow-on study, the cost consequences of variability in performance, as determined by ranges of measurable operating parameters, were estimated through the use of a face production simulation program (CONSIM). By examining a typical continuous mining development section, insights were gained regarding the impact of such criteria as payload, discharge time, tram speed, and haul distance, on performance outcome measures, such as production rate, percent time waiting for a shuttle car, and st per shuttle car mile. The clear implication is that operator proficiency frequently can be expressed in terms of observable quantities (weights, rates, and times) and that some operating variables (e.g., payload) have a larger cost significance than others (e.g., tram rate, and discharge time). For the section layout used in this study, increases in tram speed over baseline conditions, for example, were seen to increase productivity only modestly. This finding suggests that the cost consequences of errors associated with unsafe tram speeds, including injuries, glancing blows, equipment damage, and component wear, can, in no way, be offset by productivity gains.

In sum, the WCPM introduced in this report represents an empirically-based research model that provides a framework for developing practical strategies for identifying human factors and training needs *at the working section*. It comes at a time in which further significant gains in both safety and productivity likely will come about not through technologic advances, but rather by enhancements in overall system effectiveness (66). Most of these enhancements will be made possible through the upgrading of so-called "soft-skill technologies," aimed at reducing variability in individual performance and at effecting a continuous improvement in performance. The WCPM provides a framework for designing and implementing intervention strategies. It can be used to help bring an individual to an initial adequate level of competence. To maintain or improve performance, and to tie the worker's contribution to organizational accomplishment. From the managerial viewpoint, the WCPM can be used to conceptualize, measure and rate performance, to rationally explain performance variability, and to improve the quality of supervision. The use of the nominal group technique (Q-sort) to obtain input and learn from experienced crew

members is of value as a method for capturing the high levels of expertise that reside within a veteran work force.

The WCPM can serve to heighten the awareness of the mining industry's need for: (1) defining and ranking job elements through structured task analyses; (2) developing and testing observational techniques to establish performance baselines and to measure variability; (3) linking job competencies to a cost base; and (4) applying performance-based intervention strategies appropriate for both novice and experienced personnel. Moreover, it begins to provide incentives to mining companies for strengthening investments in the work force. These

investments can facilitate a cogent linkage between the human resource function and its impact on safety and productivity.

Finally, it is maintained that practical use of the WCPM methodology offers a continuous thread of data to define realistic goals for successive improvement within the management system, the mining system, and the work crew itself. A better understanding of operator and system variability, through economically justified on-site interventions, can serve to institutionalize continued investments in the work force through the application of human factors and human resource technologies.

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APPENDIX A.—FOUNDATIONS FOR THE WORK CREW PERFORMANCE MODEL

Early work focused on determining the types of shuttle car operator errors that occur with some frequency.¹ Two sources of data were used: (1) accident and injury data from the Mine Safety and Health Administration's Health and Safety Analysis Center (HSAC) and (2) structured interviews with experienced shuttle car operators.

A total of 914 accidents involving operation of shuttle cars over a two-year period were segregated into the behaviors and/or conditions related to the nature of the accident (1) failure to maintain control, (2) run into and/or over foreign objects, (3) rough bottom, (4) body outside compartment, (5) personal protective gear, (6) roof and rib hazards, and (7) all others.

Accident frequency in categories (1) and (2) appeared to decrease as a proportion of the total as job tenure increased. This suggested that job contingencies are such that related operator skills improve over time and that modifications to initial operator training might have an impact. Accidents in category (4) appeared just as likely to involve experienced as inexperienced operators. Accidents in categories (3), (5), and (6) represented a larger proportion of the total for experienced than for inexperienced operators. This suggests the need for performance evaluations and interventions that maintain performance over the long term and supports the industry's need for improved strategies of "performance management." These needs exist whether errors that lead to accidents are due to changes in exposure to conditions or situations characterized by higher numbers of accidents or to a real degradation of operator's skills due to lack of discriminative cues, performance feedback, or practice.

To obtain inference regarding types of errors most often associated with shuttle car injuries or accidents with high cost consequences, structured interviews were conducted with experienced shuttle car operators from several major coal producers. A concise list of types of operating errors most often associated with shuttle car accidents or

injuries with a high negative impact on the long-term cost of producing coal was constructed (24).²

- Cutting or pulling cables apart.
- Hitting the miner from behind.
- Not switching direction of lights when loading.
- Pulling away from the miner before shutting off conveyor.
- Overloading to the point of spillage.
- Traveling faster than the rate of cable reel pick-up.
- Traveling at high rates of speed.
- Raising boom while moving toward loading point.
- Failing to judge correct rate while dumping onto conveyor.
- Failing to judge shuttle car's position on feeder.

Incidents associated with the occurrence of these errors are seldom reportable injuries (since injuries are *rare* consequences of system failures and/or human error), but they do either directly or indirectly result in financial loss. However, several of the errors listed above can be related to the most frequently reported accidents. For example, traveling faster than the rate of cable reel pick-up or traveling faster than conditions dictate can lead to failure to maintain control.

The most important finding in this early research phase was that each identified error is *observable* and can be linked to probable minor injuries, equipment damage, downtime delays, or production decrement, as shown in the partial task analysis in table A-1. Moreover, this tentative list of behaviors would lead later to the construction of a variety of performance indicators to be sampled in evaluating an operator's set of skills on the job or the transfer of learning from the training situation to the job site. These observable cues would allow the differentiation among the operators. The WCPM begins to answer such questions as:

1. How can training be used effectively with other intervention strategies to eliminate errors with high cost consequences? How can performance be further enhanced by improving the supervisor's ability to discriminate between significant and less significant operator performance errors?
2. Can the cost-effectiveness of training be maximized by more realistically linking errors to the cost of the consequences, considering both the *average cost* of an

¹Bureau research has targeted the shuttle car operation for the following reasons:

1. This operation has a high incidence of operating accidents that could be attributed to unsafe behaviors or conditions.
2. Reasonably well constructed checklists of appropriate or desired behaviors exist for this operation, which can be used as cues as a part of a JSA or in developing SOPs.
3. Bringing shuttle car operators to a skill level adequate for routine performance was viewed to be easier than for other room-and-pillar job classifications, leading researchers to hypothesize that error profiles for shuttle car operators could be used as correlates to outcome measures (e.g., downtime and productivity) for this pilot study.

²Italic numbers in parentheses refer to items in the list of references preceding these appendixes.

incidence of the error and the *frequency* with which the error occurs?

3. Can each of the identified errors be used to track the underlying cause of the error and develop performance improvement strategies appropriate for the situation?

4. What are the WCPM's implications toward the development and use of JSAs and SOPs? Could the listing

of behavioral errors ranked by costliness of consequences overcome the shortcomings of the use of these forms of job safety documentation for safety performance evaluation? Could the results of the WCPM provide a guide for systematic, efficient work sampling for evaluation, as well as for the appropriate type of performance improvement strategies?

Table A-1.—Partial task analysis for shuttle car operation related to performance evaluation
Activity: Trammig the shuttle car at operational speeds

Expected performance	Common errors	Probable consequences	Cost elements
Faces direction of travel	Veers from side to side, hangs out of pit to see.	Accident—injuries, damage to ribs; slow trammig.	Injury costs (medical treatment, benefits, time off); equipment repair.
Keeps all parts of body inside	Hangs out of pit to see	Accident—injuries	Injury costs (as above).
Keeps car on straight path . .	Veers from side to side even with good bottom.	Damage to ribs; slow trammig	Reduced load rate; damage to buggy.
Stops for people in roadway; uses warning device.	Fails to stop	Buggy jolts—pinning co-workers.	Injury costs or fatality.
Travels at correct speed	Travels too fast; fails to judge how well cable is picking up.	Hitting rut—jamming neck; spill-on roadway.	Injury costs or fatality; violation; downtime.
	Travels too slowly	NAP	Possible production decrement.
Trams with boom fully lowered.	Leaves boom up	Hitting top; bolt breakage	Damage to shuttle car; delay to replace bolts and/or timber.
Keeps track of own cable and other cables.	Runs over, cuts cables, hangs out of pit to see cable.	Cable splice required; injury . .	Downtime; cable replacement; injury costs.
Uses correct procedure to pass through ventilation curtain.	Forgets warning; fails to wait for response; walks through to check in middle of roadway.	Injury; equipment damage . . .	Injury costs; equipment repair.

Source: Adapted from Wiehagen, Digman, and Goeke (24).

APPENDIX B.—UNDERPINNING OF THE WORK CREW PERFORMANCE MODEL: MEASURES OF TRAINING EFFECTIVENESS

Many researchers and practitioners have noted the difficulties in the measuring of training impact. Cited as reasons for the lack of training assessment are: (1) confusion and frustration inherent in identifying training objectives common to the variety of participants involved in training decisions; (2) interdisciplinary conflicts (e.g., between economists and psychologists) as to what to measure and how; (3) technical difficulties involved in producing rate-of-return estimates (e.g., ensuring sample representativeness, maintaining internal validity, especially by removing sources of method, observer, and selection bias); (4) difficulty in estimating the true cost of implementing performance improvement strategies; and (5) the view by some that the value of accurate, and oftentimes sophisticated, rate-of-return information may be overshadowed by the costs of obtaining such information (17).

Perhaps the overriding reason for the lack of information on training effectiveness however, has been a lack of knowledge and applied research of useful performance measurement techniques that make sense to training practitioners, veteran workers, and front-line supervisors. Training can be evaluated in a number of ways (15, 19). Unfortunately, references to "instructor evaluation" rather than "evaluation of accomplishment" are most common. Reactions of learners to the training program are most often collected, even though studies have shown that such reactions do not necessarily have any consistent or predictive relationship to measures of learning (pre-tests and post-tests) or performance (training transfer).

CURRENT STATUS

Typical bottom line evaluations of training in general industry tend to focus on improving both work life *quality* (measured through injury data) and *profit* (measured through productivity). Clearly, both measures of training impact are too broad or too generic to be useful in justifying long-term performance improvement programs, particularly for single-site studies. The major problems associated with using injury data and productivity as measures of training effectiveness is summarized below.

Injury Data

A fundamental problem with injury data as measures of training effectiveness is the appearance that the objective is to teach workers not to have accidents. In fact, injuries are rare events for particular mine sites. Because the number of incidents is small and the expected frequency rates are often in a predictable range, even if statistically

significant changes could be shown, the generalization of the results would be suspect at best. Moreover, using injury data collected long after training to measure the effectiveness of that training would imply a belief that the treatment, whatever it was, would have more impact on performance than extended practice and day-to-day reinforcements that are part of the normal work environment.

Many alternative factors that could markedly influence injury rates other than training could be advanced. For example, a mining firm could significantly reduce its Non-fatal Days Lost (NFDL) injury rate simply by working with the local medical and mining communities to encourage individuals to return to work at the earliest possible date. Differential utilization of human factors technologies to reduce or eliminate the consequences of human error would influence the exposure of miners to environmental and task-specific hazards at the work site and hence the likelihood of injuries. On the other hand, a mining firm could have a training program well grounded within job and crew coordination skills and worker competence, yet still show no statistical changes in injury patterns. This could be due to an already low injury rate or to the law of diminishing returns from training or practice, or any one or combination of other possible explanations completely divorced from training issues. These points argue against the design of training effect studies centering around injury rates. Even well designed research efforts can lack the resolution necessary to separate effects due to training and those due to other intervening variables. Stated simply, injury data are just too broad, too easily influenced by other effects, and too rare for easy capture and explanation using simple analytical methods to be useful measures of training impact outside of a few weeks or months following the training.

Productivity Data

Mine productivity measures (tons of mined material per minute, per shift, or per full-time equivalent employee) are as problematic if not more so than injury and lost-time measures when used as assessments of training effect. A key problem is that productivity measures are often based on estimates of efforts rather than on calculations of actual costs of producing. In most cases, only aggregate measures are available. Frequently, this information is based on summary data that merely reflects static, cross-sectional conditions at specific points in time. Moreover, such measures are notoriously insensitive to differences in training or performance and provide no help in identifying areas where human performance could or should be

improved or where specific methods for upgrading performance might be better employed. They provide no clues as to whether a performance improvement strategy should be based on better teacher training, modified training content and/or methods, more frequent skill maintenance training, increased supervision, task analysis and redesign, better equipment, or on modified company policies. Compounding the problem is the observation that actual improvements in production, as in safety, are rarely the result of a single treatment implemented in isolation. Intervening variables include (1) performance of other crew members, (2) technologic changes and machine maintenance, (3) the effects of supervision, and (4) possible changes in the mining environment. In addition, possible effects that might further confound the analysis include: (1) the effects of informal peer group modeling; (2) reactivity of measurement, especially the knowledge of being observed; (3) sources of internal invalidity, such as history, maturation, and statistical regression; (4) observer bias; (5) selection bias; and (6) the possible effects of goal setting.

A BEHAVIORAL APPROACH

Because, to a large extent, the current impact of training investments on injury rates, job performance, or productivity is unknown, an unfortunate situation has been created for training departments that often must justify their value to the organization in terms of bottom line profitability. This can contribute to an atmosphere not conducive to the accomplishment of the vital tasks of assessing training needs and developing innovative training programs. One purpose for developing the WCPM is to permit HRD investments to be more in tune with the real purposes for training; to develop a capability that does not yet exist or to maintain and reinforce an existing high level of skill. Another purpose is to provide an approach to making performance improvement decisions that are more systematic and analytical than the common "qualitative" approach.

Defining the relevant accomplishment of the job is critical; without such, neither the initial level of competence nor the exemplary level of performance can be defined or measured. Even the U.S. Army, which is probably the world leader in training effectiveness research, admits that it "has achieved little, if any, success at developing an integrated system for measuring training

performance and using the results to improve the training of its individuals and units" (27).

To measure the quality of training, variables reflecting training effectiveness, but independent of day-to-day circumstances, need to be used. Such variables would be related to the primary job accomplishment defined for the position. For example, the primary job accomplishment for a shuttle car operator might be described in terms of productivity, as "hauls 500 tons per shift." However, a better measure is, simply, "minimizes the miner operator's time waiting for an empty shuttle car."

One approach to assessing operators' work behavior is based on defined activities necessary to accomplish the job. This approach utilizes checklists of appropriate or desired behaviors. Lists of behaviors have been prepared by many developers of training materials and by industrial personnel. These lists of cues typically are used as part of a JSA or in developing SOPs. Not all of the items, however, define performance errors that *significantly* impact the operator's job accomplishment. Obviously, some job tasks are viewed as more important than others. In the absence of quantitative data, these distinctions or judgments are dependent on either the performer or the observer. The practical utility of these lists is limited without associated information about the relative frequencies of these cues and the probabilities that occurrence of these cues will have a direct and important impact on the performance of the work crew or the mine section.

Furthermore, front line supervisors have limited resources for the evaluation of performance. Providing them with a rational and efficient means for conducting work site observations would significantly improve both the impact of initial training and the long-term performance of the worker.

Once observable cues are identified and ranked, the problem can then be defined in terms conducive to operations research and to implementation of performance improvement strategies (including training and evaluation). A cost-benefit assessment of skill would be based on observing those behaviors under the direct control of the equipment operator that, in the case of the shuttle car operation, for example, can increase or reduce wait time by the continuous miner operator for an empty shuttle car. An analysis of error patterns and associations between errors and factors related to injuries, downtime, production decrement, and property damage, become critical elements in such an assessment.

APPENDIX C.—DETAILS OF THE Q-SORT PROCEDURE

Initially, each participant was given a stack of 58 cards containing activity descriptions and asked independently to divide the stack into low and high priority groups. Cards from each of these two stacks were again sorted into high and low priority groups (yielding four stacks), with the middle two groups combined to form the Medium group. Each participant then divided the low and high priority groups into two subgroups each, again on the basis of perceived priority. Activities in the lower subgroup of the low priority group received an initial rating of very low;

those in the higher priority subgroup of the low priority group were rated low. Activities in the lower subgroup of the high priority group received an initial rating of high; those in the higher subgroup of the higher priority group received an initial rating of very high. After each participant had rated all activities, the results were tabulated and summarized to determine the composite group rating and degree of prevailing consensus for each activity. Figure C-1 summarizes the Q-sort procedure used in this study.

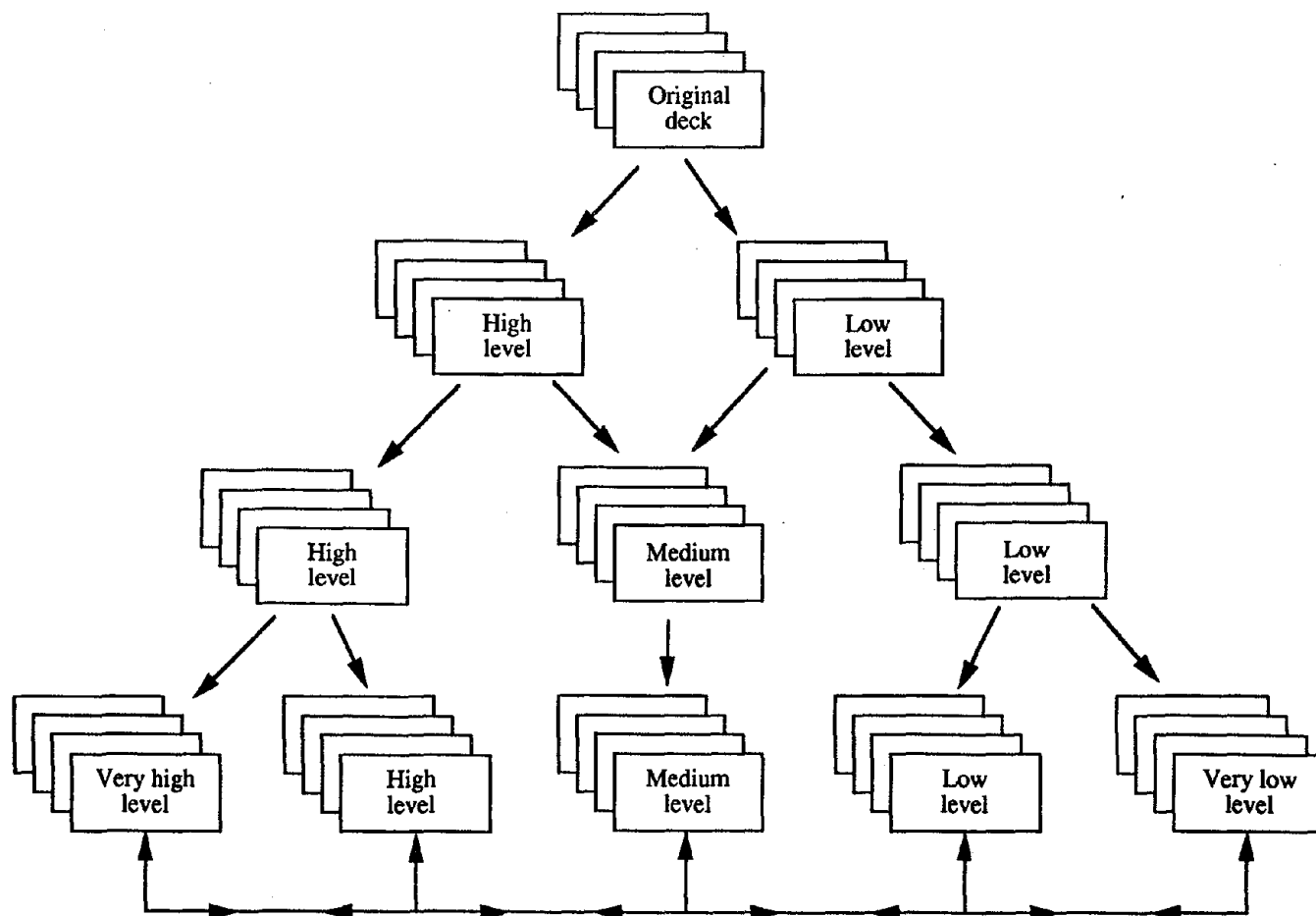


Figure C-1.—Q-sort procedure for ranking job activities by cost consequences.

APPENDIX D.—IMPLICATIONS OF THE ANALYSIS OF SHUTTLE CAR DOWNTIME DATA

Company records had several shortcomings for research purposes:

1. Records did not indicate which individual was operating the shuttle car when a downtime incident occurred. Without this information, it was not possible to associate the downtime data with the proficiency profiles of individual operators.

2. The downtime data gave no clue regarding how many reported incidents were carry-overs from the previous shift. Both shuttle cars studied had more incidents of downtime reported for the first shift than for the second shift (table 4 in text). Nevertheless, some of the instances reported for the second shift may have occurred originally on the first. Since the machine would still be unavailable at the start of the second shift, additional downtime would be reported.

3. The narrative descriptions of events surrounding downtime incidents were inadequate for research purposes in terms of clearly delineating the root causes of the downtime event. For example, a cable downtime incident might have been accompanied by a remark: "Splice cable." This remark does not explain why the cable required splicing. An improved narrative might be: "Splice cable - operator caught cable when leaving feeder." Improved narrative descriptions would aid in determining which incidents might be attributable to operator error and which might be the result of component wear, improper maintenance, and equipment degradation.

Production downtime results in increased unit cost; therefore, most mining companies are able to cost a minute of production downtime. Downtime data appear to have considerable utility for determining the cost consequences of performance errors. However, before such data can be used extensively for tracking costs, improvements need to be made to the manner in which the data are reported.

To improve the mine's data collection capabilities, a Supplemental Shuttle Car Downtime Report Form (figure D-1) was put into use by the cooperating mine. When a downtime incident involving a shuttle car is reported to the company dispatcher, this person requests further information, especially: (1) the name of the machine operator; (2) the status of the operator (regular or incidental); (3) the exact nature of the downtime incident; (4) whether this incident is a carry-over from a previous shift; and (5) whether, in the opinion of the supervisor, operator error was a contributing factor in the incident.

The report form provides the link between individuals and company data on machine status necessary for a

research design. Unfortunately, however, it also adds to the paperwork burden of the reporting process. Efficient implementation of the WCPM would incorporate these or other modifications into the routine SOPs of the company.

Despite the strong possibility that the quality of downtime data contributed greatly to the lack of a conclusive relationship between shuttle car downtime and the performance results obtained by the observational techniques employed in the WCPM methodology, there are other possible explanations, including:

1. *Quantity of data.* In this study, there were practical limits on the duration of the on-site study, the number of subjects, and the number of observations per task activity.

2. *Refinements in the WCPM methodology.* Although a careful process of identifying and ranking task activities was used, the possibility exists that some activities with critical cost implications might have been omitted. Replication of the Q-sort procedure would help settle this issue. Also, it is likely that a greater research return could have been realized if it had been feasible to (1) collect total daily productivity measures for each subject (e.g., st per shuttle car mile), (2) collect data over a period longer than 3 weeks, (3) increase the state variables to reflect such factors as feeder load condition upon beginning of the dump segment of the duty cycle and amount of precut coal ready to be loaded into the shuttle car upon arrival at the miner, (4) collect subjective self-reports of errors over the 3-week period and a ranking of subjects' skill levels, as perceived by co-workers and supervisors. Also of interest would have been the study of the influence of possible confounding variables (e.g., shift time, age, experience, personality measures, and training differences) on both the performance measures and the cost effect data, which was not possible in this study.

3. *Improvements in the WCPM design.* As presently constituted, the model focuses on likely cost consequences of variability in behavioral job performance. This focus, although consistent with the recent research evidence in the areas of assessment and performance improvement (67-69), does not rule out the impact of work design factors and working conditions on performance. Examples of these factors, many of which are traditionally used as correlates of performance outcomes include: (1) shift and schedule specification at observation point; (2) operator background (e.g., training, experience, age, personality, and attitude); (3) ergonomic demands (e.g., movement, noise, vibration, glare, sight lines, posture, and control positions); and (4) external stressors (e.g., sensory feedback distractions, production or supervisory demands, and internal stimuli). Because behavior is the aggregate of *observable*

responses to stimuli, and since it may be argued that measures of performance based on behavior can be related more directly to what an employee actually does, it remains the preferred criterion measure for assessing job

performance, for recommending intervention strategies, and for assessing their effectiveness in applied settings (70-71).

SHUTTLE CAR STATUS REPORT

Mine No.:	Location:	Date:
Supervisor:	Sect. No.: 1 2 3 4 5 6 7 8 9	Shift: 1 2 3

SC Number	Operator Name	Opr. Status		DELAY MINUTES		Code	REASONS	Opr. Error			Carry Over	
		Reg.	Incid.	TOTAL	LOAD			Y	N	U	Y	N

Figure D-1.—Supplemental Shuttle Car Downtime Report Form.

APPENDIX E.—ADDITIONAL CONSIM RESULTS

Figure E-1 (related to figure 5 in text) demonstrates the utility of CONSIM in obtaining the interrelationships among variability in operating parameters and outcome measures. Figures E-1A and E-1B show that (1) at a near-optimum payload, an increase in discharge time has little effect on time to load out the cut sequence (and therefore on load rate); and (2) as payload decreases, the effect on time to load increases. A convenient criterion outcome measure is given in figure E-2, which shows that the measure, st per shuttle car mile, predictably decreases with decrements in payload, but not necessarily proportionally, perhaps because of (1) the complex interactions among payload and other operating parameters, and (2)

the effect of variance in partial loads in clean-up cars for each of the 77 cuts in the sequence.

Figure E-3A shows the relationship between time to load out a sequence of cuts and shuttle car dump time, holding payload constant at 7.20 st and varying the discharge time $\pm 35\%$ from the base case value of 0.56 min. Time to load the cut sequence varied linearly with discharge time, even for decreases in discharge time below the base case value of 0.56 min. Holding load rate constant in the simulation runs removed the variability in miner operator proficiency. Figure E-3B shows the relationship between percentage of shift time waiting for a shuttle car and discharge time, again holding payload constant at 7.20 st. A detention of the shuttle car at the dump due to increases in discharge time results in slightly increased shuttle car wait time and, as shown in figure 5 in the text, a small production decrement.

Figure E-4A shows how time to load the cut sequence varies with payload. Here, it is interesting to note that the production rate levels off at its theoretical maximum near 7 st; beyond this payload, there is no further significant production rate gain. Figure E-4B shows the greater impact on shuttle car wait time brought about by increases in payload. In fact, wait time virtually disappears with payloads in the 8- to 10-st range.

Figure E-5 (related to figure 6 in text) shows the relatively minor impact of tram rate increase on percent time

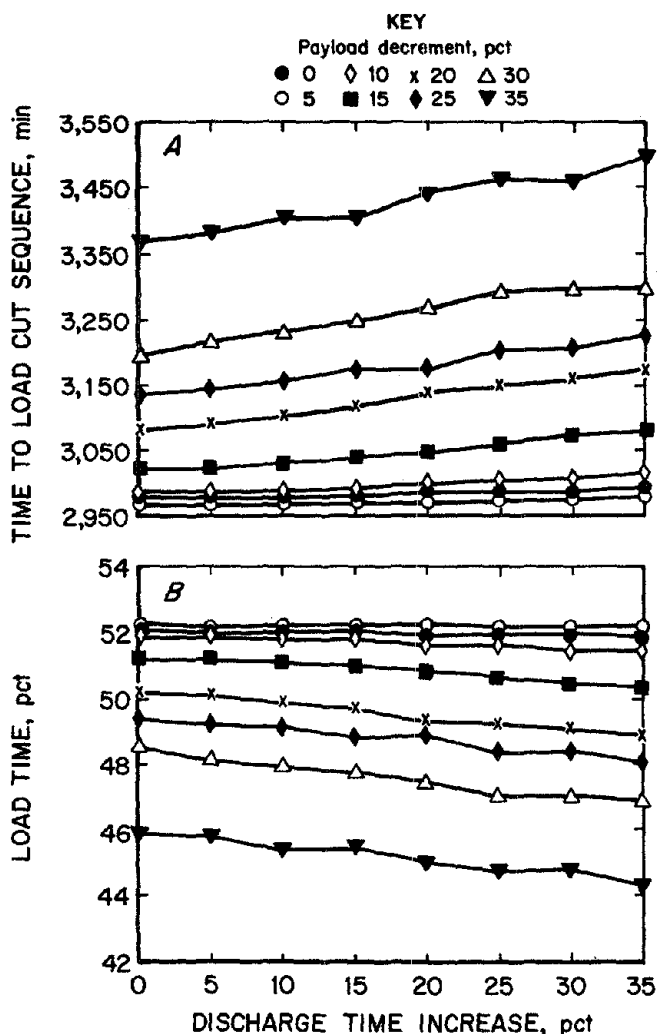


Figure E-1.—Simulation results; interrelationships among payload decrement, discharge time increase, and various performance outcome measures.

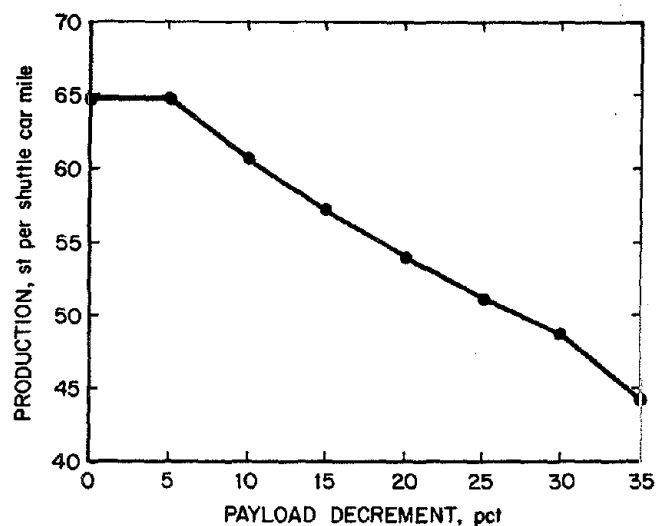


Figure E-2.—Simulation results; relationship between payload decrement and one performance outcome measure, st per shuttle car mile; base case tram rates, 0.56 min discharge time.

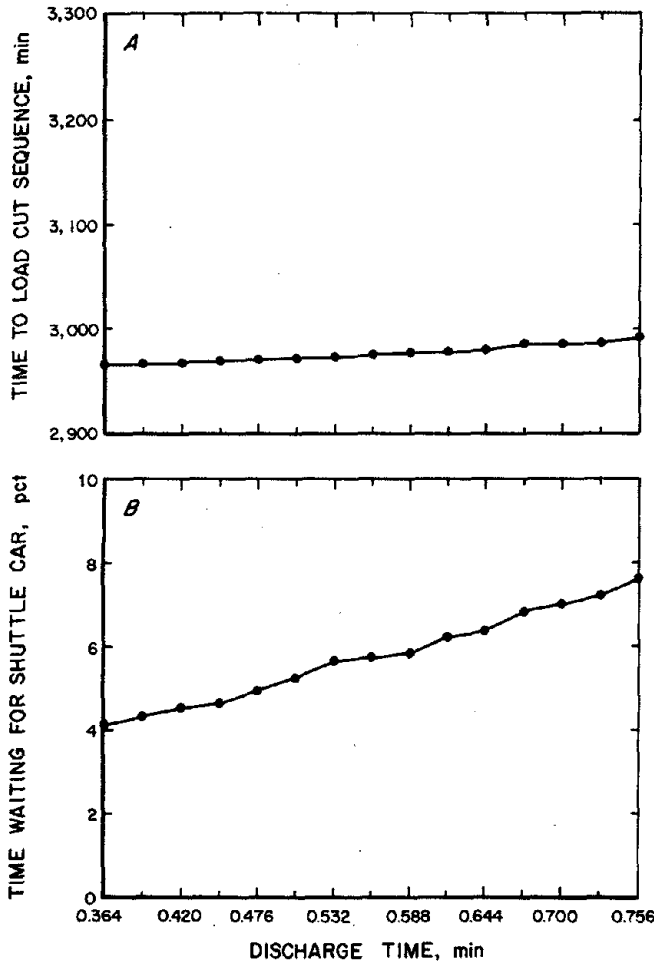


Figure E-3.—Simulation results; relationship between discharge time and performance outcome measures; base case tram rates, 7.20 st payload.

waiting for a shuttle car. Had average haul distance been longer and/or payload smaller, however, the effect of tram rate on these output measures could have been quite different.

Finally, figure E-6 summarizes the results of an investigation into the effect of increases in average haul distance (simulated by incrementing discharge change out distance) on such measures as st per shuttle car mile (E-6A), production rate (E-6B), and percent time waiting for a shuttle car (E-6C). This provides an example of the use of CONSIM to evaluate the effect of alternate organizational interventions (e.g., modifying management policy toward timing of belt moves) on productivity. As one would expect, st per shuttle car mile and production rate both *decrease* and percent time waiting for a shuttle car *increases* with an increase in haul distance.

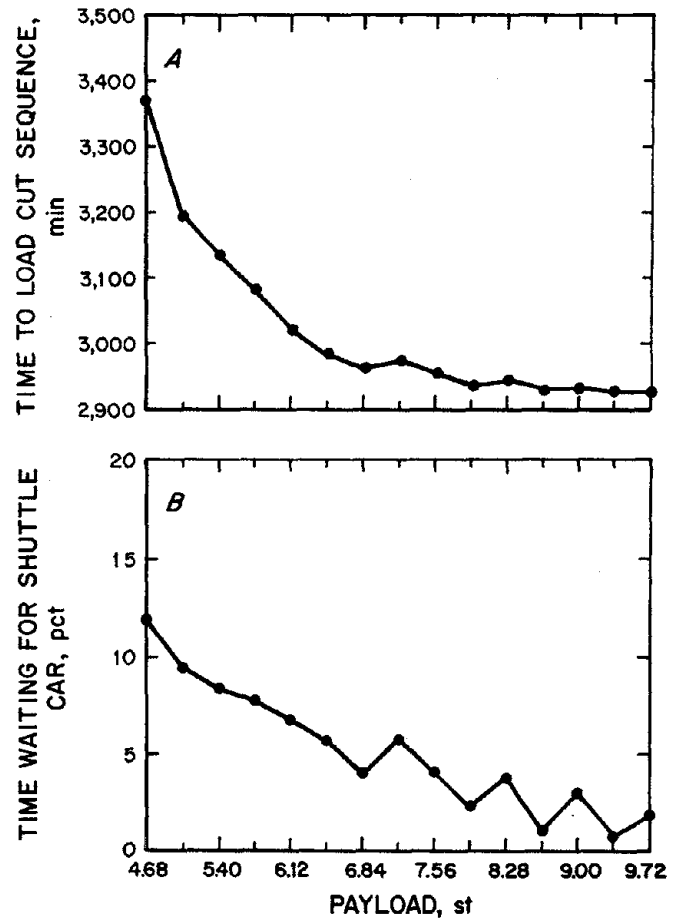


Figure E-4.—Simulation results; relationship between payload and performance outcome measures; base case tram rates, 0.56 min discharge time.

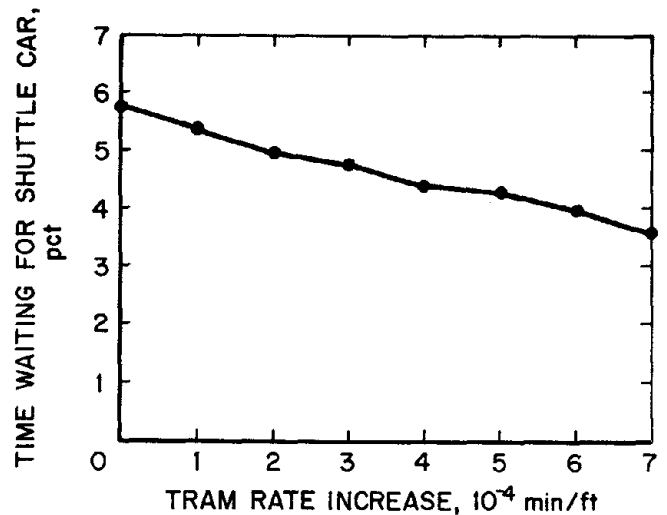


Figure E-5.—Simulation results; effect of tram speed increase on time waiting for a shuttle car; 7.20 st payload, 0.56 min discharge time.

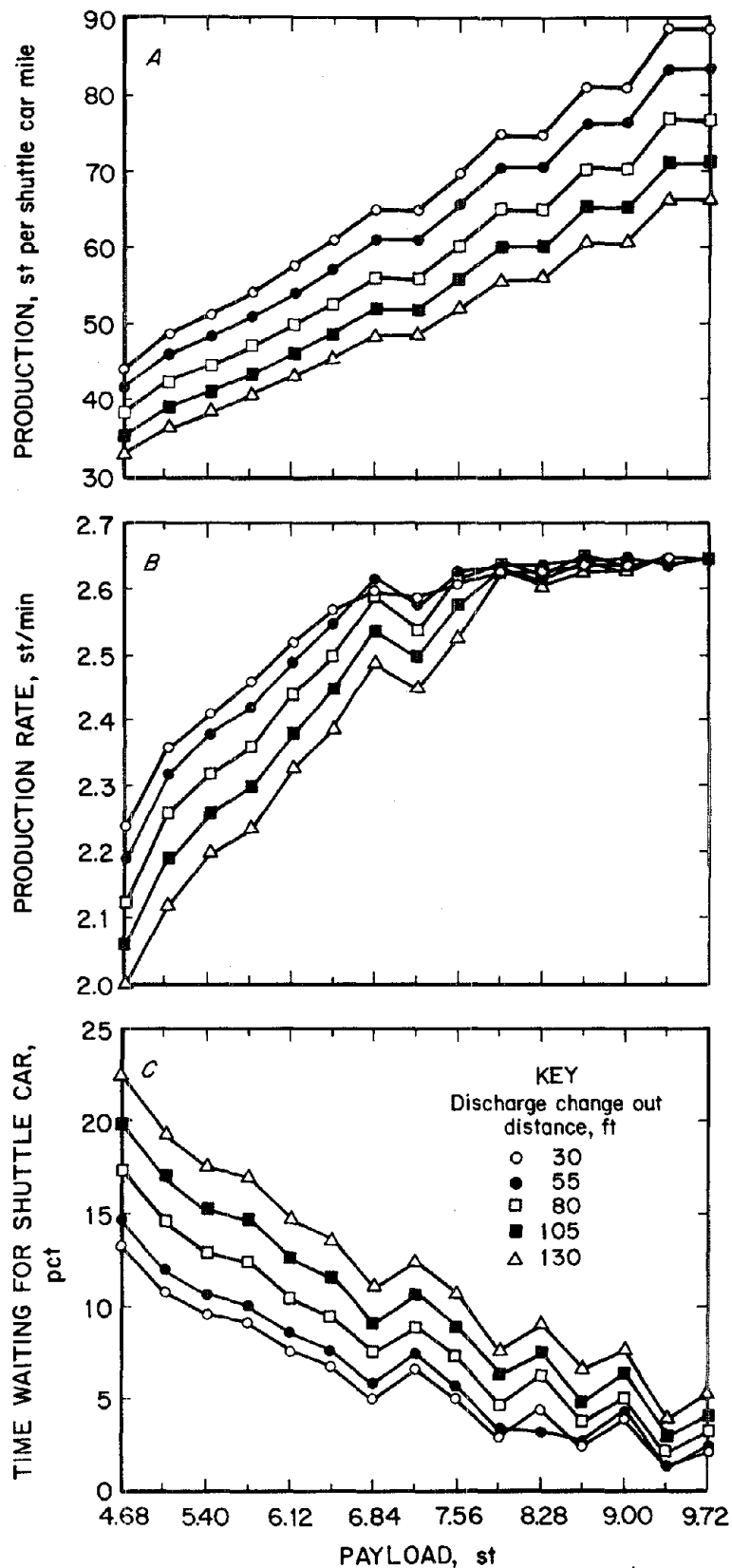


Figure E-6.—Simulation results; interrelationships among payload, haul distance, and various performance outcome measures.