Research and Test Department

# AN ERGONOMIC INVESTIGATION OF HAND SWITCH OPERATION

R-715

George B. Page
Paul B. McMahan

Washington Systems Center

ASSOCIATION OF AMERICAN RAILROADS

# AN ERGONOMIC INVESTIGATION OF HAND SWITCH OPERATION

R-715

George B. Page
Paul B. McMahan

April, 1990

Safety Research Division
Research and Test Department
Association of American Railroads

## DISCLAIMER

This document was prepared and disseminated under the sponsorship of the Association of American Railroads (AAR). The AAR assumes no liability if the results or recommendations presented herein are used in an environment or context different than that described in the report.

This document is disseminated for informational purposes only. It is given to, and accepted by, the recipient at its sole risk. The AAR makes no representations or warranties, either express or implied, with respect to the information in this document or results derived from its use. The AAR assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential or any other kind of damage resulting from the use or application of the information contained in this document. Any attempt to apply the information derived from use of this document is done at the recipient's own risk.

| 1. REPORT NO. | 2. REPORT DATE | 3. PERIOD COVERED |
|---|---|---|
| R-715 | April 1990 | |

**4. TITLE AND SUBTITLE**

An Ergonomic Investigation Of Hand Switch Operation

**5. AUTHOR(S)**

Mr. George B. Page, Senior Safety Research Engineer
Mr. Paul B. McMahan, Manager Safety Research Division

| 6. PERFORMING ORGANIZATION NAME AND ADDRESS | 7. TYPE OF REPORT |
|---|---|
| Association Of American Railroads, and<br>Center For Ergonomics<br>University Of Michigan<br>Ann Arbor, Michigan 48109-2117 | Research<br>**8. Contract No.**<br>ESD-87-024 |

| 9. SPONSORING AGENCY NAME AND ADDRESS | 10. NO OF PAGES |
|---|---|
| Association Of American Railroads<br>Research And Test Department<br>50 F Street, NW<br>Washington, DC 20001 | 72<br>**11. NO. OF REFERENCES**<br>7 |

**12. SUPPLEMENTARY NOTES**

Contact Mr. George B. Page, (202) 639-2266, for further information.

## 13. ABSTRACT

About 4 percent of all lost time injuries in the railroad industry are associated with the operation of hand switches. These injuries cost about $30 million a year in claims. We investigated the operation of vertically operated, ground level switch stands. We used biomechanics to evaluate methods workers use to operate this type of switch stand. We found some operating methods to be less stressful than others. We developed procedures to that could be used to compare the back compression experienced and strength needed by workers with guidelines for back compression and strength that have been established by the National Institute for Occupational Safety and Health (NIOSH). We also found that current procedures for maintenance of switches and switch stands, when applied to the switches we evaluated, reduced (on average) the forces needed to move the lever arm so that the back compression experienced and strength needed of the worker were within the NIOSH guidelines. Lastly, we provide an EXAMPLE analysis of alternative designs for switch stand levers that illustrates how human performance criteria might be helpful in developing and evaluating such designs.

| 12. SUBJECT TERMS | 12. AVAILABILITY STATEMENT |
|---|---|
| Railroad, switch stand, switches, physical stress, over-exertion, ergonomics, low-back pain, injuries, maintenance, design, lubrication, adjustment | Full AAR members only. Contact sponsoring agency. |

This page is intentionally blank

# AN ERGONOMIC INVESTIGATION OF HAND SWITCH OPERATION

## EXECUTIVE SUMMARY

### Background

About percent of all lost time injuries in the railroad industry are associated with the operation of hand switches. Annual claims and suits from these injuries are estimated to be about $30 million. Yard workers and road trainmen account for over 92 percent of the cases. And 43% of all injuries involve the lower back.

Workers perceive that operating hand switches is one of the most frequent and can be one of the most difficult tasks they perform. Overall, about 18% of yardmen lost time injuries are associated with operating hand switches.

The Association of American Railroads (AAR) and the Center for Ergonomics at the University of Michigan performed an ergonomic investigation of yardmen activities as part of a cooperative research effort to determine why these injuries occur and what can be done to prevent them.

### Approach

We limited this study to the evaluation of the operation of two vertically operated "ground throw" switch stand types. We classified the methods workers use to operate these switch stand types by analyzing video recordings of workers. We then used a 3-dimensional biomechanical model to evaluate each of these method classifications to determine which allow workers to safely exert the greatest hand forces (defined below) upon the lever arm.

We also developed human performance criteria that could be used to identify and evaluate alternative switch stand designs. These criteria are based, in part, on the strength and back compression limits recommended by the National Institute for Occupational Safety and Health (NIOSH) in their publication *Work Practices Guide for Manual Lifting*. They represent *estimates* of the hand forces workers can exert on the switch lever handle while keeping the levels of back compression and strength needed within guidelines established by NIOSH and while maintaining their balance. We present these human performance criteria as a function of switch stand lever angle.

We then measured the forces needed to operate 77 switch stand levers by smoothly pulling and pushing on a gauge that was attached at a point on the lever handles where the worker's hands would be located. We measured the forces perpendicularly to the switch stand lever at seven angles as we moved the lever through its arc. And we took repeated measurements to assure consistency.

Throughout this report we made the simplifying assumption that: to operate the switch stands we evaluated, workers must apply forces of the same magnitude and in the same direction (i.e., perpendicular to the lever) as our force measurements by pulling or pushing with their hands. Further, we assume that smooth controlled movements are made so that little or no inertial effects are present. We refer to these forces as the "**hand forces needed**" to operate the switch.

We show, in this report, the usefulness of the human performance criteria we developed by using them to evaluate the measured hand forces from 77 switch stands.

Finally, we performed a mathematical evaluation of the possible effects of changes in two switch stand design parameters: the length of the switch stand lever and the weight of its handle. This evaluation demonstrates how the human performance criteria can be used to help evaluate switch stand design alternatives.

## Findings With Regards To Worker Methods

We found that some of the method classifications we evaluated are better than others. That is, they permit the worker to exert greater force on the switch stand lever while minimizing both the back compression experienced and the strength needed. The following methods for lifting the switch stand handle and general findings for operating the switch stand appear to help minimize both back compression and the strength needed by the worker.

*Methods For Lifting The Switch Handle That Permitted The Largest Hand Forces While Being Within The Capability Of Most Workers*

(1) *Symmetric Squat Lift.* Begin the squat lift (legs mostly bent) with the feet centered on the switch stand lever handle. Use two hands.

(2) Stoop Lift. Begin the stoop lift (legs mostly straight) with the feet centered on either the switch stand lever handle (preferred) or the tie closest to the handle. Use either one or two hands.

(3) Stoop Lift With Target Support. Begin the stoop lift (legs mostly straight) with the feet centered on either the switch stand lever handle (preferred) or the tie closest to the handle. Perform the lift with one hand placed on the switch stand target for support. This lifting method may reduce low-back stress and probably improves balance. However, we did not investigate whether there are other hazards associated with its use.

*General Findings Regarding The Operation Of Hand Switches*

(1) *Shift Feet.* Shifting of the feet while moving the switch stand lever helps ensure smooth movements that require minimum

reach and take advantage of the workers' strength. Generally, we observed that the movement of the lever involves three steps as follows:

| | |
|---|---|
| Lift | Lift the lever to about the 60° position - 1/3 of the movement. Then *shift the feet* in the direction of movement and prepare for the next step. |
| Transition | Move the lever to about the 120° position - 2/3 of the movement. |
| Set | Move the lever to the "set" position, about 180°, to complete the movement. |

(2) *Stand Close To The Lever.* Staying as close as possible to the lever during all phases of movement helps minimize stress on the low-back and takes advantage of the worker's strength by minimizing reach. To stay close, you must shift the feet in the direction of the movement of the lever.

(3) *Use Smooth Controlled Movements.* Smooth movements performed in a controlled (i.e. planned) manner help to minimize low-back stress and muscle strain. Many circumstances can cause the condition of a switch to change suddenly. Thus, it is important that workers approach and operate each switch stand with caution—not expecting its condition to be the same as the last time. Using smooth controlled movements can help the worker adjust to the uncertain and changing condition of switches. (Note: methods that do not involve smooth movements but rather use rapid, jerky, highly dynamic and highly forceful movements were not evaluated in this project)

(4) *Use "Foot Stomp" With Caution.* Pressing down on the lever with the foot to finish the movement reduces the need for bending and thereby reduces the associated low-back stress. The "foot stomp" variation is used on some railroads. Other railroads do not agree with or permit its use. We did not evaluate the "foot stomp" variation. Accordingly, we cannot recommend for or against its use.

(5) *Remove Foot From Keeper Release When Possible.* The keeper, on switches so equipped, is released by stepping on the release lever. Two conditions occur during the release of the keeper.

*Switch Lever Releases Automatically*. In some cases the switch stand lever will automatically move up beyond the keeper's catch when the release lever is stepped on due to tension in the switch mechanism. When this happens the worker can remove his foot from the keeper release and is free to use a more comfortable posture.

Switch Lever Must Be Moved. In some cases the switch lever must be lifted manually up beyond the keeper's catch. When this happens the worker uses a split leg posture, keeping one foot on the keeper release lever during the lift. This usually forces the worker to use one of the stoop lift categories listed above because he has insufficient reach to perform a squat lift with a split leg posture.

(6) *"Hammer" The Lever With Caution.* In situations where the switch is difficult to operate, workers sometimes move the lever back and forth with a "hammering" action to complete the movement of the switch stand lever. Such hammering action may produce sufficient inertia in the switch handle to generate the forces necessary to operate the switch. We do not know whether there is a physical "penalty" associated with generating this inertia. However, occupational biomechanics experts generally do not recommend the use of rapid, jerky, highly dynamic, and/or highly forceful movements during lifting, lowering, pushing, or pulling tasks.

The following findings may also prove useful in helping to reduce the number and severity of injuries associated with switch stand operation.

**Other Findings**

- The forces needed to move the switch stand lever arm (i.e., orthogonal hand forces assuming smooth motions) can be measured using a simple force gauge and procedure outlined in this report. The measurements obtained from this procedure are repeatable, valid, and unbiased if performed carefully.

- Current switch maintenance procedures (cleaning, lubrication, and adjustment of connecting rods) seem to be effective at reducing the forces needed to move the lever arm. However, these procedures do not appear to significantly reduce the forces needed to lift the lever arm at the beginning of operation.

- The hand force measurement procedure we developed (See Appendix A) and the human performance criteria based on the NIOSH Guidelines might be used to develop and evaluate effective switch stand maintenance practices, including maintenance frequency and type of maintenance.

- The human performance criteria and hand force measurement procedure may also be helpful in the initial installation and adjustment of new or replacement switch stands. If the measured hand forces are too high, compared to the human performance criteria, and a cause can be found, then action might be taken to reduce the hand forces.

- Improvements in switch stand design may lower the forces needed to operate switch stand levers. Our example analysis of design alternatives for switch stand levers illustrates how design guidelines based on human performance criteria could be developed for handle weight and mechanical advantage provided by the switch stand—including the lever.

- Design improvements for these ground operated switch stands could be based on performance specifications that satisfy biomechanical and other ergonomic criteria. However, compliance with such criteria should not require excessive periodic switch maintenance. Any such design improvements would obviously have to be based on technical and economic feasibility.

This page is intentionally blank

## Table Of Contents

## List Of Figures

# List Of Tables

## ACKNOWLEDGEMENTS

We owe many thanks to all those among the railroads that participated in our study. They gave us their time and effort to help organize and participate in our field work. And they were tolerant of our endless questions.

First, we owe special thanks to those at Consolidated Rail Corporation for allowing us to combine our research efforts with theirs. In particular, we thank William Field and Robert Dedow for devising the hand force gauge measurement method we used and evaluated in this study. Their efforts helped develop a simple yet accurate way to evaluate hand switch stands. We also thank William Field and Dave Cargill for performing field tests on prototype switch stand levers, and contributing their findings to this report. This study benefits significantly from their efforts. We also thank, Neil Ferrone, and Bob Weir for their assistance. And we thank Mike Mitchell and Jim Fenley for supporting our investigation with a fully cooperative staff.

We thank those at CSX Transportation for being the first to assist us in our project. Several people gave us endless support and time out of their hectic schedules. They include: Gary Branch, Mike Donahue, Larry Ellison, Al Fritts, Jimmy Horner, Jim Kozal, Ed Lehrke, Gary Morison, Robert Schofield, Marv Slatton, Walt Vanderveer, and William Wyatt. And special thanks go to Jeff Blomgren.

We thank those at Norfolk Southern whose help we enlisted and they enthusiastically provided. They include: Lou Hale, Dave Harness, and Jim Overholser.

Thanks go to Todd Brown and Steve Kuciemba for carefully reviewing and commenting on this report. Several people carefully reviewed and commented on this paper. They include Jack Buckingham, Lou Cerny, Tom Hatchard, Albert Reinschmidt, Mike Rougas, and Mike Rush. To all, thanks.

And finally, we wish to thank those at the Center for Ergonomics at the University of Michigan. Carter Kerk helped us develop and direct this study and perform much of the biomechanical analysis. We appreciate his endless receptiveness to our ideas and understanding of our problems. We thank Don Chaffin for his guidance in the application of basic biomechanics. And thanks go to Chuck Woolley and James Foulke for their creation of the electronic hand force and lever angle measurement system. We also thank James Foulke for carefully reviewing this paper. For their assistance in adapting the 3-dimensional static strength model and the torso muscle model to our task, we thank Richard Hughes and M. Erig. We further thank Richard Hughes for his assistance with the analysis using the torso muscle model. And we thank Teryl Lynn for the artistic renderings of this task.

# AN ERGONOMIC INVESTIGATION OF HAND SWITCH OPERATION

## 1.1 Background

Injury statistics reported by U.S. railroads to the Federal Railroad Administration reveal that the industry incurs about 14,000 lost time injuries annually. This represents about 4.5 lost-time injuries per 100 workers per year. Payments for injury claims and suits under the Federal Employers' Liability Act (FELA) amounted to $748 million in 1988.

Railroad yardmen account for about 16% of the industry's lost time injuries while working just 8% of all man-hours. The lost time injury rate for yardmen increased during the 1984-1987 period from 6 to about 9 lost time injuries per 100 workers per year. This is double the overall injury rate for the industry. The estimated cost of yardmen injuries (in claims and suits) has also increased steadily during 1984-1987 from $243,519 to over $500,000 per 100 workers per year–or $5,000 per year for each worker.

The Association of American Railroads (AAR) and the Center for Ergonomics at the University of Michigan performed an ergonomic investigation of yardmen activities as part of a cooperative research effort to determine why these injuries occur and what can be done to prevent them. We identified the the following primary tasks that yardmen perform by using interviews with workers and on-site observations: mounting and dismounting cars, coupling (including adjusting drawbars) and uncoupling cars, operating hand switch stands, setting and releasing hand brakes, and walking in the yard.

From our interviews we determined that workers perceive the operation of hand switch stands as one of the most difficult and frequent tasks they perform. Injury statistics confirm this finding. Significant lost time injuries are attributable to operating switches. Nationally, over 18 percent of yardmen lost time injuries are associated with hand operated switches. Forty-three percent of these injuries involve the lower back.

The costs of injuries attributable to the operation of hand switches is high. We estimate that the industry pays about $30 million a year (in 1988 dollars) in claims and suits for injuries associated with switch stand operation. This is a conservative estimate that is computed by multiplying the percentage of lost days associated with such injuries by the total cost of claims and suits from all injuries in 1988. It assumes that the cost of such injuries is directly proportional to the percentage of lost days associated with such injuries (i.e. 4%). However, one major railroad has estimated their cost of claims and suits for these injuries at over $10 million in 1988. This suggests that such injuries may actually account for a higher percentage of the claims and suit payouts than previously expected. One possible explanation for this is that switch-related injuries may have a higher overall severity than injuries from other causes.

## 2.0 Objectives

We performed an ergonomic analysis to identify ways to improve safety in the use of hand-operated switch stands. The specific objectives of this analysis were to:

(1) identify the general categories of methods workers use to operate switch stands and determine which are least stressful,

(2) develop an objective method to determine whether the forces a worker uses to operate a hand switch (assuming smooth motions) conform to human performance guidelines, for back compression and strength, suggested by the National Institute for Occupational Safety and Health (NIOSH),

(3) determine whether the the forces a worker uses to operate a hand switch (assuming smooth motions and the use of the methods evaluated in this study) can be made to conform to the human performance guidelines mentioned above through the use of current maintenance procedures (Note: we did not evaluate maintenance practices).

(4) demonstrate how human performance criteria can be helpful in evaluating possible switch stand design alternatives.

## 3.0 Study Approach Overview

We completed the following basic steps to achieve the stated objectives of this project.

(1) Collected and reviewed video recordings of many of the methods that workers use to operate switch stands. We then grouped these methods into general categories (e.g. stoop, squat, fixed feet, one-handed, etc.) for biomechanical analysis.

(2) Performed biomechanical analyses of general categories of workers' methods to determine which are least stressful with respect to back compression and strength required.

(3) We developed human performance criteria for switch stand evaluation and design. These criteria are based, in part, on the strength and back compression limits described by the NIOSH Work Practices Guideline. They represent *estimates* of the forces workers can exert on the switch stand handle while keeping the levels of back compression and strength needed to move the handle within guidelines established by NIOSH and while maintaining their balance.

(4) Developed a simple procedure for measuring the forces workers need to exert on the switch stand handle (hand forces) to operate individual switch stands (i.e. assuming smooth motions by the worker, a procedure for measuring the quasi-static hand force that needs to be applied perpendicular to the switch stand handle).

(5) Measured the hand forces needed (assuming orthogonal application of the force and smooth motions) to operate a sample of in-service switch stands both before and after typical maintenance procedures (e.g. cleaning, lubricating, and adjusting the connecting rods). Compared these forces with human performance criteria.

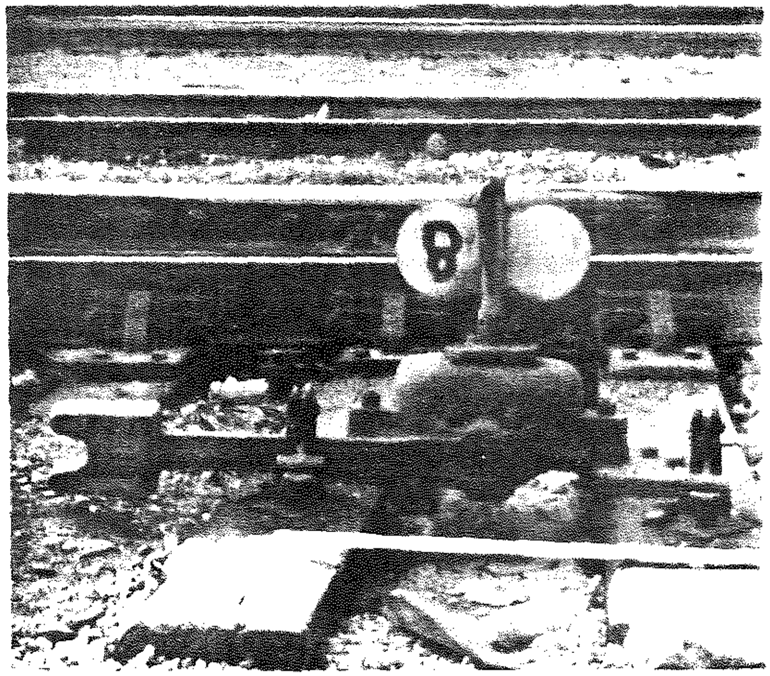
(6) Demonstrated the use of human performance criteria in the investigation of switch stand design alternatives that might reduce the forces needed to move the switch stand lever.

Switch operation safety involves more than how difficult or easy it is to operate the switch stand lever. This study did not investigate all the elements of switch operation safety, but focused on worker methods and the forces needed to move the switch stand lever.

## 4.0 Switch Stand Types Evaluated

We evaluated two vertically operated, ground level switch stand types: the Bethlehem New Century Models 50A and 51A (Figure 1, Top) and the Racor Model 22-P (Figure 1, Bottom). These two switch stand types are representative of a general category of switch stands referred to as "ground throw." We were not able to evaluate every type of "ground throw" switch stand. However, our analysis of worker's methods and the human performance criteria we present should be applicable to other switch stands that fit into this general category (i.e., if they are of a similar dimensions, and have similar operating characteristics).

The operating levers of both of these switch stands move in a vertical plane parallel to the rail. The lever begins in a horizontal position (approximately) and is moved manually from left-to-right or from right-to-left with respect to the operator. The lever ends in a horizontal position after moving about 180° from the starting position. Relative to the movement of the switch points, the travel of the operating lever can be broken into three parts: (1) one switch point is released from the stock rail as the operating lever is lifted, (2) the switch points then move to the opposite side of the track as the switch lever is "pushed" or "pulled" through the middle portion of the travel, and (3) the opposite point is pressed against the opposite stock rail when the switch lever is pushed down into the final position. There may be considerable variability in the location of the beginning and ending points of these phases, depending upon the switch stand's design and adjustment, among other factors.



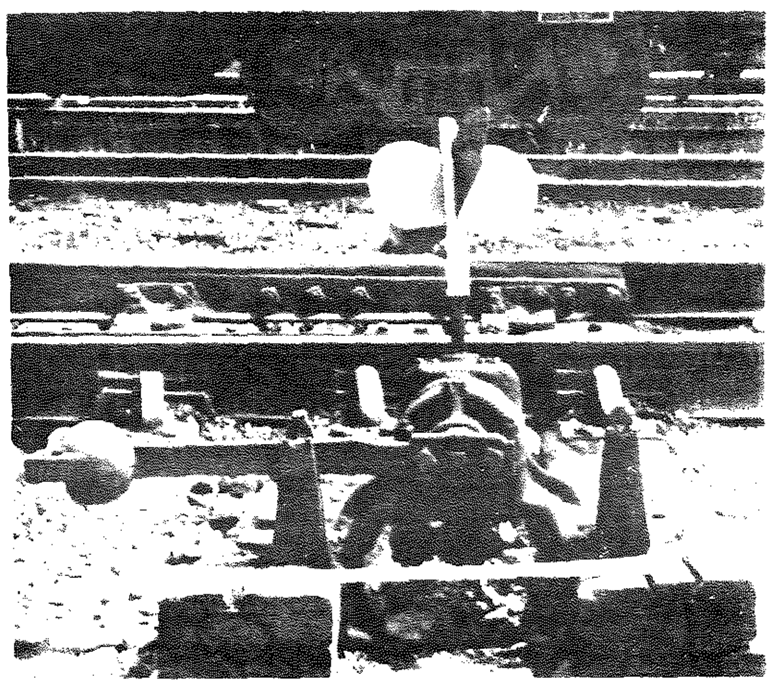


Figure 1
A New Century Model 51A Switch Stand (top)
A Racor Model 22P Switch Stand (bottom)

Both switch stand types have a weight incorporated into the handle at the end of the lever. The weight of the handle on the New Century switch stand levers we examined was either 30 or 35 pounds. The handle on the Racor switch stand levers we examined weighed 10 or 17 pounds. The weight of the handle assists the operator in lowering the switch stand lever over the last 90° of operation. But this weight must also be lifted by the operator over the first 90° of operation.

The New Century switch stand uses a safety latch or "keeper" to ensure that the lever remains closed as rail cars move through the switch. To start the movement, the operator must release the latch either by lifting the upper latch with a hand or depressing the lower latch with a foot. At the end of the movement, the switch stand lever must be pushed down until the latch is secured. The Racor switch stand does not have a latch because its internal mechanism permits "run-throughs" without affecting switch stand lever orientation.

The length of all the switch points we evaluated was 16 feet 6 inches. Some of the heel blocks were fixed and some were floating. The rail section of the switch rail ranged from 105 to 133 pounds per yard.

## 5.0 Categories Of Worker's Operating Methods

Workers use various methods to operate the switch stands. It was not within the scope of this project to perform a biomechanical analysis of each specific method. Such analyses are very difficult and costly. So, in order to simplify our analysis, we decided to group the specific methods we observed into general categories (e.g. stoop, squat, fixed feet, one-handed, etc.) for biomechanical analysis. In addition to on-site observations of worker's methods, we collected video recordings covering over 20 workers, 50 switches, and three yards. We stopped collecting new video recordings of individual methods when our review of the recordings failed to reveal new general categories. Our findings are thus applicable and relevant to many of the specific methods that workers use that fit within the general categories we identified.

Before explaining the general categories of methods, it is necessary to define the sign conventions that we used. Our reference system describes worker operating methods and the motions of the switch stand lever with respect to the operator. The operator stands facing the switch stand as shown in Figure 2. The right-hand side of the operator is the positive side and the left-hand side of the operator is negative. The angle of the switch stand lever is 0° when upright, +90° when horizontally right, and -90° when horizontally left as shown in Figure 3. We describe each method category in terms of switch stand lever movement from right to left (+90° to -90°). We found that the method workers use to perform the task from left-to-right is, in general, the mirror image of their right-to-left method.

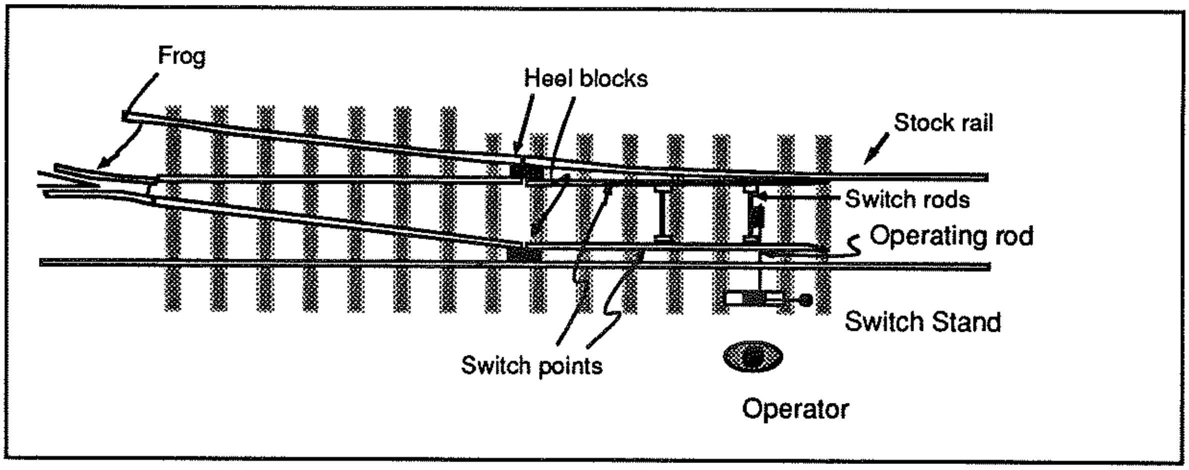



Figure 2.
Top View Of An Operator, A Switch Stand, And A Switch

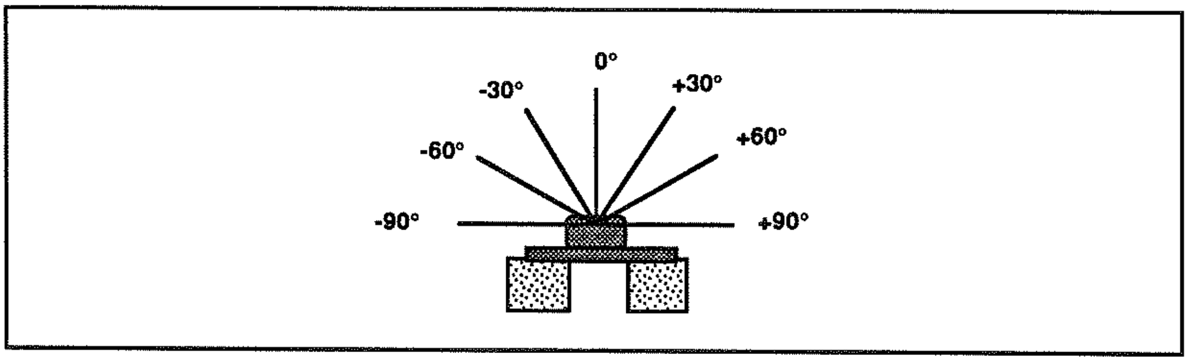



Figure 3.
Angle Convention Of The Lever Arm From
The Perspective Of The Operator

We identified four basic categories of methods workers use to operate these hand switch stand models. Two of the method categories use a stoop lift to begin the movement of the switch stand lever, while two of the method categories use a squat lift to begin the movement.

In the stoop lift category, the operator tends to keep the legs mostly straight and flex the torso forward far enough so that a straight arm can reach the handle of the lever. We identified two basic variations of the stoop lift method category. These are classified by whether or not the operator's feet move to complete the operation. If the feet begin centered on the switch stand, the operator may or may not shift his feet. If the feet begin centered on the handle or on the tie closest to the handle, then a shift of the feet is necessary. In most cases, the shift ends with the feet centered on the opposite tie. Figure 4 (top) illustrates the stoop lift method category.

In the squat lift category, the operator bends at the knees and flexes forward with the torso (but not nearly as much as with the stoop lift) so both straight arms can reach the handle of the lever. Figure 4 (bottom) illustrates this method category. We identified two basic variations in the squat lift method category. These variations are classified by the symmetry or asymmetry of the lift performed at the beginning of the lever movement. If the feet are centered on the switch stand lever handle (i.e. the ball), the method is symmetrical. When the feet are centered on the tie closest to the handle, the worker must reach to his right (or left) to lift the handle. Thus this variation is asymmetrical because it requires twisting and lateral bending of the torso.

We also identified two other method variations that are sometimes used. One, the "foot stomp" method, is commonly used to complete switch stand lever movement. The operator simply steps down on the handle with his foot. The other method variation involves the switch stand target, if one is present. Operators sometimes place their free hand on the target for support during a one-handed stoop lift (see Figure 5). This method may help stabilize balance and increase leverage while lifting the handle of the switch stand lever.

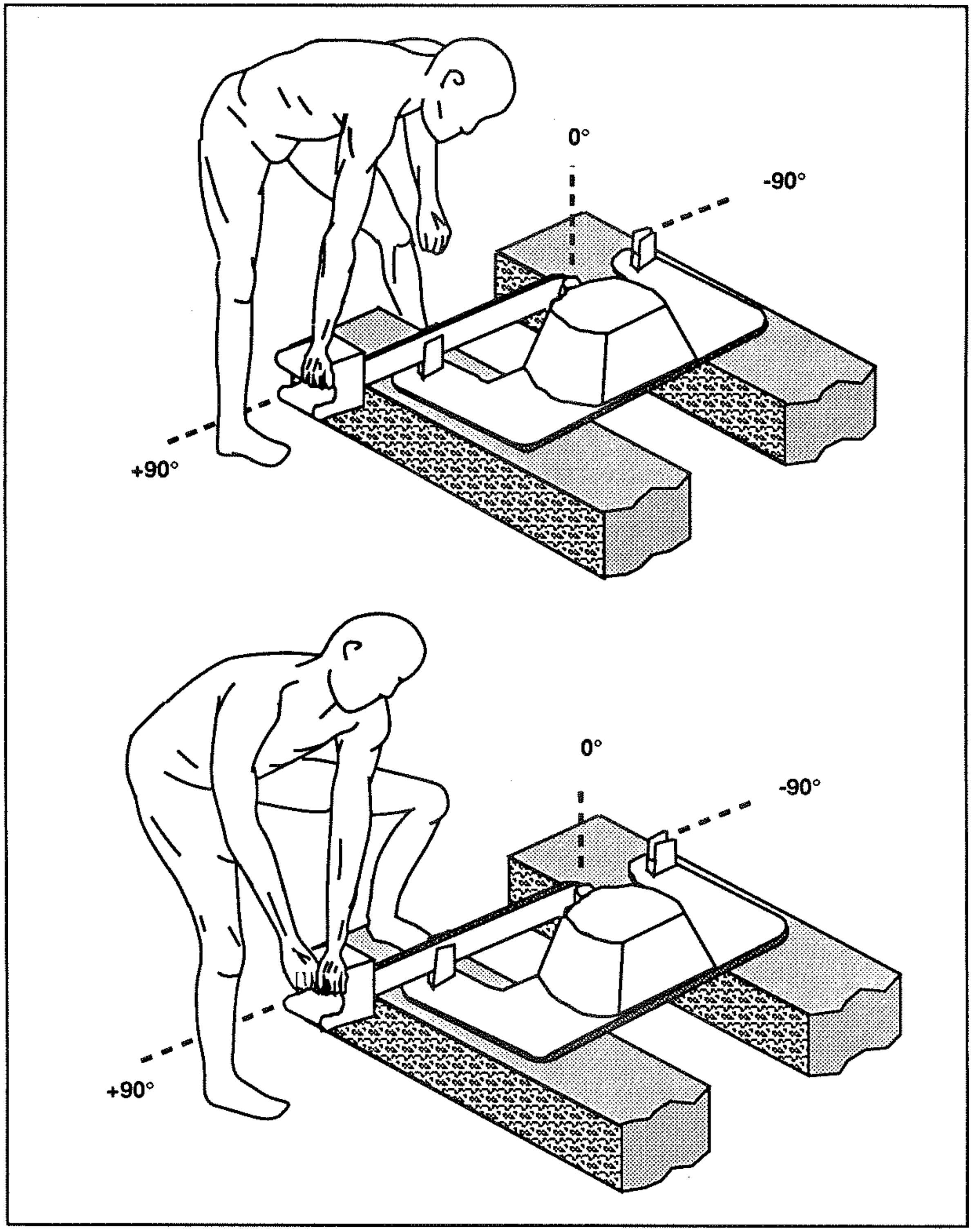



Figure 4.
Stoop Lift Method (top) And Squat Lift Method (bottom)
To Operate A Hand Switch Stand

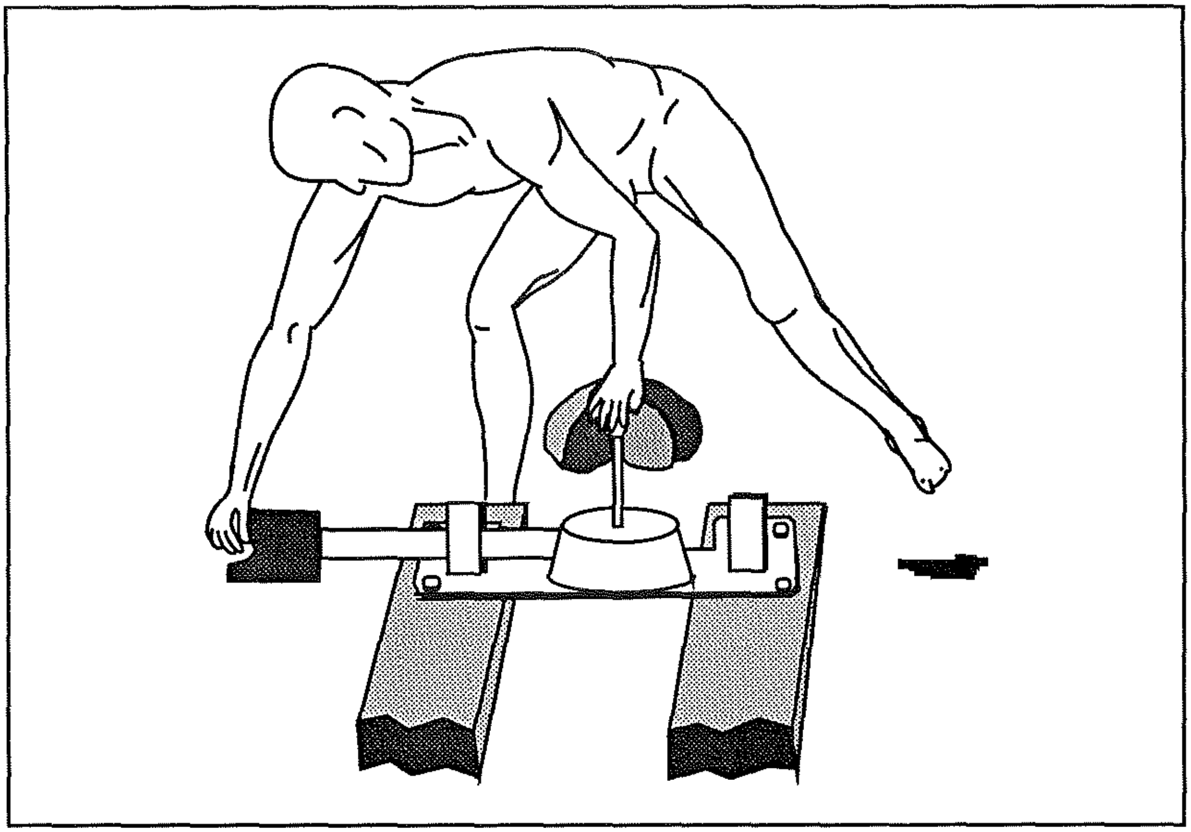


Figure 5.
Variation Of The Stoop Lift Method. The Operator Places
The Free Hand On The Switch Stand Target

## 6.0 Basis For Evaluation Of Operating Methods And Developing Human Performance Criteria

We evaluated the basic method categories described above using a three-dimensional biomechanical model (University of Michigan, 1988). Inputs to this model consist of: (1) the posture of the worker (i.e. his method), (2) the size of the worker, and (3) the magnitude and direction of the force exerted on the worker's hands. The model then computes the forces at various locations in the body (e.g., the elbow, shoulder, and lower back). The model uses this information to: (1) estimate the level of compression in the lower back, (2) estimate the strength required of the worker at various locations in the body, and (3) determine if the worker can maintain safe balance. (Details regarding how these estimates are computed can be found in the documentation of the model.)

The model is useful because of its ability to evaluate asymmetric postures of the upper body. However it does have the following limitations:

- This is a static model used to evaluate a dynamic task by breaking it down into discrete quasi-static sub-task elements. This is a common practice by occupational biomechanics professionals. It is the only acceptable alternative because three-dimensional dynamic models have not, at this time, been developed, validated, and made readily available. Thus this model does not consider any inertial effects that may be produced by workers' methods. This includes methods that involve the use of quick or jerky movements. We expect that inertial effects might *increase* back compression estimates at certain lever locations (particularly when the switch stand lever is initially lifted). However, inertial effects might *decrease* back compression estimates at other lever locations. This decrease might occur because inertial forces, already generated by prior acceleration of the switch stand lever can be used to complete its movement. If the task is performed in a highly dynamic manner with high inertial forces, our derived human performance criteria *might* be too high at the initial lift and too low at other locations. When this task is performed with smooth controlled motions, the inertial effects are assumed to be minimal.

- The strength prediction routine of this model estimates static strength capability. However, much research has shown that human dynamic strength capabilities are lower than static strength capabilities. Thus worker strength capabilities may be overestimated by this model when workers use quick, jerky methods. Under such conditions our human performance criteria would be too high (i.e. not sufficiently restrictive and overstate human capability).

- Furthermore, our evaluation does not consider the frequency at which workers operate switch stands/switches. Nor does our study consider the duration of the work shift. It is well documented that human strength and endurance capabilities decrease when frequencies and task duration reach a level where recovery and rest of the muscles is not complete. *If such conditions exist* in switching operations then our derived human performance criteria would be too high (i.e. not sufficiently restrictive and overstate human capabilities).

Through careful observation of the video recordings and photographs of switch stand operation, we divided each of the method categories into a series of distinct postures. Each posture describes a "method" at one of seven locations throughout the switch stand lever's 180° arc. The seven switch stand lever angles are: +90°, +60°, +30°, 0°, -30°, -60°, and -90°.

Because reach affects the posture a worker uses, worker size (anthropometry) must be considered in our biomechanical analysis. To do so, we evaluated two anthropometric conditions for each distinct posture at each switch stand lever location. One anthropometric condition represents a large, 95th percentile man operating the stand (i.e. only 5 percent of the adult male population is larger and weighs more). The other anthropometric condition represents a small man of 5th percentile stature and weight (i.e. only 5 percent of the adult male population is smaller and weighs less). In total, we evaluated 118 different postures that represent the range of individual methods workers use.

Our evaluation sought to identify those method categories that permitted the highest hand forces while satisfying each of three ergonomic criteria. Table 1 below shows that the three criteria deal with human tolerance to levels of back compression, human strength capabilities, and balance. We sought to identify those method categories that satisfy the lower limit of human capability shown in Table 1. Such method categories will be within the capability of approximately 95% of workers.

Table 1.
Ergonomic Criteria For Identifying Best Methods
For Operating Hand Switches

| | **Ergonomic Criteria** | |
|---|---|---|
| **Model Estimate** | **Lower Limit Of Human Capability** | **Upper Limit Of Human Capability** |
| Back compression in the lower back. | Back compression in the lower back (L5/S1 disc) should not exceed the "Action Limit" value for back compression established by the National Institute for Occupational Safety and Health (NIOSH). | Back compression in the lower back (L5/S1 disc) should not exceed the "Maximum Permissible Limit" value for back compression established by NIOSH. |
| Static strength required at various locations in the body (e.g. arms, shoulders, back, etc.) for each distinct posture evaluated. | The strength required by the task should not exceed the "Action Limit" value for static muscle strength established by NIOSH. | The strength required by the task should not exceed the "Maximum Permissible Limit" value for static muscle strength established by NIOSH. |
| Balance | The worker should remain in static equilibrium (i.e. balance) while performing the task. | The worker should remain in static equilibrium (i.e. balance) while performing the task. |

Note: For more information on the basis and application of the NIOSH "Action Limit" and "Maximum Permissible Limit" values mentioned in the above table, consult the publication "Work Practices Guide For Manual Lifting" (NIOSH 1981). Appendix B also summarizes the NIOSH Work Practices Guide.

## 7.0 Evaluation Of Methods Categories

We evaluated each of the 118 distinct postures with the biomechanical model. We increased the hand force input to the model in five pound increments until the model predicted that either back compression, strength, or balance would exceed the lower limit of human capability shown in Table 1. Thus, we identified and recorded the value of the highest hand force that satisfied the lower limit of human capability. We refer to this value as the maximum allowable hand force. We repeated this procedure for each of the seven distinct postures that made up each of the method categories discussed above.

By comparing the maximum allowable hand forces thus derived for each of the method categories we evaluated, we were able to identify those method categories that allow workers to exert the largest hand forces. The following methods for lifting the switch handle and other general findings regarding methods for operating hand switches were thus identified.

*Methods For Lifting The Switch Handle That Permitted The Largest Hand Forces While Being Within The Capability Of Most Workers*

(1) *Symmetric Squat Lift.* Begin the squat lift (legs mostly bent) with the feet centered on the switch stand lever handle. Use two hands.

(2) *Stoop Lift.* Begin the stoop lift (legs mostly straight) with the feet centered on either the switch stand lever handle (preferred) or the tie closest to the handle. Use either one or two hands.

(3) *Stoop Lift With Target Support.* Begin the stoop lift (legs mostly straight) with the feet centered on either the switch stand lever handle (preferred) or the tie closest to the handle. Perform the lift with one hand placed on the switch stand target for support. This lifting method may reduce low-back stress and probably improves balance. However, we did not investigate whether there are other hazards associated with its use.

*General Findings Regarding The Operation Of Hand Switches*

(1) *Shift Feet.* Shifting of the feet while moving the switch stand lever helps ensure smooth movements that require minimum reach and take advantage of the workers' strength. Generally, we observed that the movement of the lever involves three steps as follows:

Lift — Lift the lever to about the 60° position - 1/3 of the movement. Then *shift the feet* in the direction of movement and prepare for the next step.

| | |
|---|---|
| Transition | Move the lever to about the 120° position - 2/3 of the movement. |
| Set | Move the lever to the "set" position, about 180°, to complete the movement. |

(2) *Stand Close To The Lever.* Staying as close as possible to the lever during all phases of movement helps minimize stress on the low-back and takes advantage of the worker's strength by minimizing reach. To stay close, you must shift the feet in the direction of the movement of the lever.

(3) *Use Smooth Controlled Movements.* Smooth movements performed in a controlled (i.e. planned) manner help to minimize low-back stress and muscle strain. Many circumstances can cause the condition of a switch to change suddenly. Thus, it is important that workers approach and operate each switch stand with caution—not expecting its condition to be the same as the last time. Using smooth controlled movements can help the worker adjust to the uncertain and changing condition of switches.

(4) *Use "Foot Stomp" With Caution.* Pressing down on the lever with the foot to finish the movement reduces the need for bending and thereby reduces the associated low-back stress. The "foot stomp" variation is used on some railroads. Other railroads do not agree with or permit its use. We did not evaluate the "foot stomp" variation. Accordingly, we cannot recommend for or against its use.

(5) *Remove Foot From Keeper Release When Possible.* The keeper, on switches so equipped, is released by stepping on the release lever. Two conditions occur during the release of the keeper.

<u>Switch Lever Releases Automatically</u>. In some cases the switch stand lever will automatically move up beyond the keeper's catch when the release lever is stepped on due to tension in the switch mechanism. When this happens the worker can remove his foot from the keeper release and is free to use a more comfortable posture.

<u>Switch Lever Must Be Moved</u>. In some cases the switch lever must be lifted manually up beyond the keeper's catch. When this happens the worker uses a split leg posture, keeping one foot on the keeper release lever during the lift. This usually forces the worker to use one of the stoop lift categories listed above because he has insufficient reach to perform a squat lift with a split leg posture.

(6) *"Hammer" The Lever With Caution.* In situations where the switch is difficult to operate, workers sometimes move the lever back and forth with a "hammering" action to complete the movement of the switch stand lever. Such hammering action may produce sufficient inertia in the switch handle to generate the forces necessary to operate the switch. We do not know whether there is a physical "penalty" associated with generating this inertia. However, occupational biomechanics experts generally do not recommend the use of rapid, jerky, highly dynamic, and/or highly forceful movements during lifting, lowering, pushing, or pulling tasks.

## 8.0 Human Performance Criteria For Switch Stand Evaluation And Design

The human performance criteria we developed are based on the strength and back compression limits described by the NIOSH Work Practices Guideline. They represent ***estimates*** of the hand forces workers can exert (assuming they use smooth motions) while keeping the levels of back compression and strength needed within guidelines established by NIOSH and while maintaining their balance. These human performance criteria could be used as a tool to evaluate the forces needed to operate switch stands. If the measured hand forces are too high, compared to the human performance criteria, and a cause can be found, then action can be taken to reduce the hand forces. Additionally, these human performance criteria can be used to evaluate new (but similar in dimensions and operating characteristics) switch stand designs to determine whether the strength needed by workers (assuming smooth motions and use of the methods studied in this research) and resultant levels of back compression exceed NIOSH guidelines.

Figure 6 shows the two human performance criteria lines that we developed from our biomechanical analysis. These criteria lines represent estimates of the hand forces that would result in back compression or strength levels described by the NIOSH Action Limit (lower line) and Maximum Permissible Limit (upper line) **for male workers**. These human performance criteria assume that workers are using either the symmetric squat or the stoop lift and that they shift their feet during the movement of the switch lever. If operators do not shift their feet, the criteria lines would be 10 to 20 lbs lower at the beginning of operation (lift-up) and 20 to 25 lbs lower at the end of operation (push-down). This illustrates the importance of shifting the feet so that the body is as close to the lever handle as possible during the movement of the lever. Furthermore, the ballast is assumed to be approximately mid-way between the top and bottom of the switch timbers. The criteria lines would be lowered by about 10 pounds at the beginning of operation if the ballast is level with the top of the switch timbers, a condition that requires more bending by the operator.

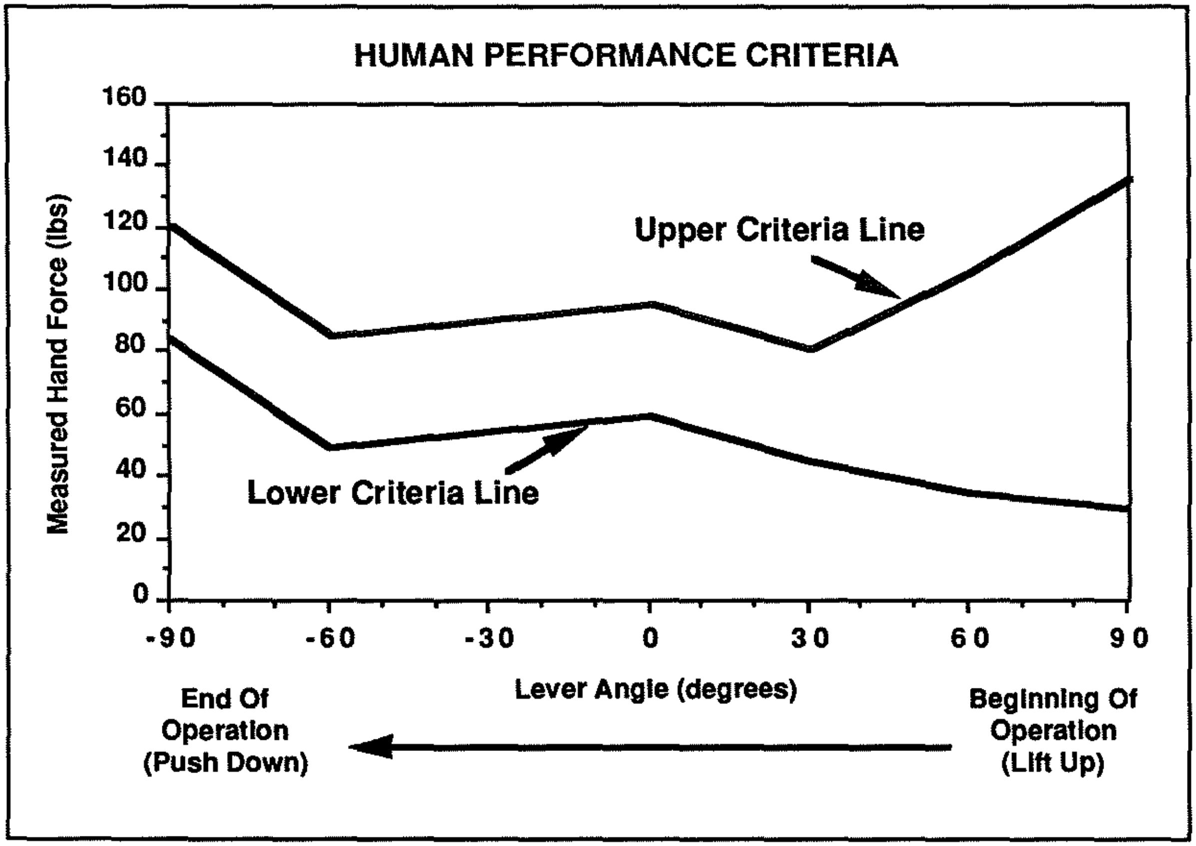



Figure 6.
Human Performance Criteria For Switch Stand Evaluation And Design

The area **above** the upper criteria line in Figure 6 is the region, for 95% of workers, where either:

- back compression levels in the lower back (L5/S1 disc) are *estimated* to be **above** the "Maximum Permissible Limit" value established by the National Institute for Occupational Safety and Health (NIOSH), or
- the strength required by the task is *estimated* to be **above** the "Maximum Permissible Limit" value for static muscle strength established by NIOSH (i.e. only 25% of male railroad workers will have sufficient strength) , or
- workers are *estimated* to be unable to maintain their balance while applying such forces.

The area **below** the lower criteria line in Figure 6 is the region, for 95% of workers, where:

- back compression levels in the lower back (L5/S1 disc) are *estimated* to be **below** the "Action Limit" value for back compression established by NIOSH, and
- the strength required by the task is *estimated* to be **below** the "Action Limit" value for static muscle strength established by NIOSH (i.e. 99% of male railroad workers should have sufficient strength), and
- workers are *estimated* to be able to maintain their balance while applying such forces.

The two criteria lines shown in Figure 4 thus form three regions for classifying measured hand forces taken from switch stands of this type as follows:

**(1)** **Above The Upper Criteria Line** - Measured hand forces that fall in this region are estimated to require strength or produce back compression levels that are above the NIOSH Maximum Permissible Limit (MPL). According to NIOSH, musculoskeletal injury and severity rates have been shown to increase significantly when work is performed above the MPL. NIOSH recommends that engineering controls (see below) be used to correct such situations.

**(2)** **Below The Lower Criteria Line** - Measured hand forces that fall in this region are estimated to require strength or produce back compression levels that are below the NIOSH Action Limit (AL) criteria. According to NIOSH, the risk of musculoskeletal injury is minimal when work is performed below the AL. NIOSH recommends that no action is required to control such risks.

**(3)** **Between The Lower and Upper Criteria Lines** - Measured hand forces that fall in this region are estimated to require strength or produce back compression levels that are between the NIOSH AL and MPL. According to NIOSH, musculoskeletal injury and severity rates begin to increase moderately when work is performed above the AL. These rates then increase significantly as the measured hand forces approach the MPL. In fact, some studies have shown a three-fold increase in rates of low-back pain incidents for jobs performed at the MPL versus the AL. NIOSH recommends the use of engineering and/or administrative controls to control injury risks for jobs performed between the AL and MPL. Engineering controls might include changes in the type and frequency of maintenance or changes in the design of switch stands and switches. Administrative controls might include selection of workers with adequate strength or teaching workers to use methods that require less strength.

## 9.0 Switch Stand Evaluation Procedure

We developed a switch stand evaluation procedure for use by individual railroads, and evaluated alternative ways of measuring the hand forces needed by workers (assuming smooth motions) to operate individual switch stands. Measurements made with a simple push/pull gauge proved to be both repeatable and accurate. And, measurements made at sectors near the beginning, middle, and end of lever movement were sufficient to identify switch stands with hand forces above the lower human performance criteria line in Figure 6.

Our switch stand evaluation procedure is presented in Appendix A. It may be separated from this report and copied for reference and use in the field. A hand force measurement data sheet is also provided along with sources for the purchase of force measurement gauges.

## 10.0 The Effectiveness Of Switch Maintenance Procedures

We measured the forces needed to operate 39 New Century and 38 Racor switch stand levers by smoothly pulling and pushing on a gauge that was attached at a point on the lever handles where the worker's hands would be located. We measured the forces perpendicularly to the switch stand lever at seven angles as we moved the lever through its arc. And we took repeated measurements to assure consistency. We refer to these measured forces as the "hand forces" needed to operate the switch.

In this analysis, a portion of the measured hand forces were taken from rail yards some time prior to the maintenance that is typically performed on switches. That is, typical switch maintenance most likely **had not been** performed on these switches for at least six weeks. A portion of our measured hand forces were also made in rail yards some time soon after typical maintenance had been performed. Typical switch maintenance most likely **had been** performed on these switches within the last six weeks.

Typical maintenance procedures consisted of:

- cleaning and lubricating the switch plates,
- lubricating the gear mechanism of the switch stand,
- adjusting the stand's bridle or connecting rod so that the switch points fit snugly against the stock rail.

The sample of switches we evaluated may or may not be representative of those in industry in general. Therefore, the findings that follow may or may not be applicable to all switches throughout the industry in general.

*The Effect of Typical Maintenance Procedures*

Figure 7 shows a comparison of the average measured hand forces from switches prior to typical switch maintenance with hand forces from switches after typical switch maintenance (defined above). New Century stands are compared in the top figure. And Racor stands are compared in the bottom figure. The human performance criteria lines for each stand type are superimposed on each figure.

The figure shows that on **average** the hand forces we measured from switches prior to typical maintenance were very near the lower criteria line. Our sample of yards and of switches measured is probably too small to be representative of the condition of switches in the industry in general. Measurements were taken from only 77 switches in 12 yards in winter, spring and summer. Furthermore, our sample is probably too small to control for differences in individual yard maintenance *practices* (i.e. the frequency with which maintenance procedures are preformed). And our sample is probably too small to control for the effects of weather.

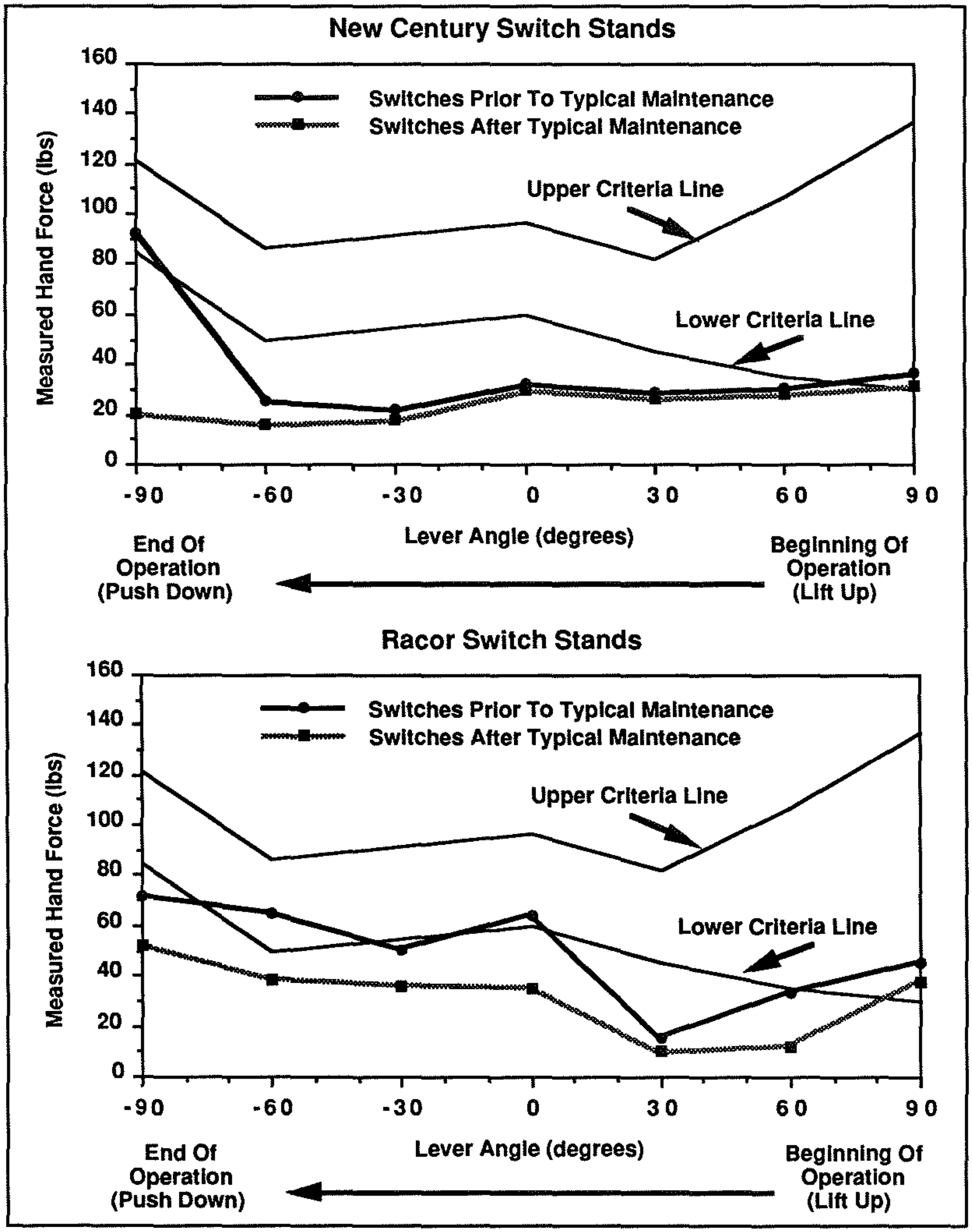



Figure 7.
Average Measured Hand Force By Switch Stand Lever Angle For Switches Prior To Versus Switches After Typical Switch Maintenance Procedures

The significant finding evident in Figure 7 is that typical maintenance procedures seem to be effective (on average) in reducing hand forces. And the benefit of typical maintenance seems to be largest at the end of the switch stand lever movement. New Century stands required on average 72 pounds less hand force at the end of switch stand lever movement. And Racor stands required 21 pounds less hand force.

*The Effect of Cleaning and Lubrication*

It is important to note that the analysis presented above only loosely controls for the time from when typical switch maintenance was preformed and when the hand forces were measured. So, although the above findings are consistent with theory, they do not prove that typical maintenance procedures can effectively reduce hand forces.

To examine the effectiveness of typical maintenance procedures further, we measured the hand forces from 5 Racor and 5 New Century stands before and immediately after cleaning and lubrication of the switch and switch stand. No adjustments were made in the connecting rods so that we could investigate the effects of cleaning and lubrication alone. Figure 8 shows the effect of cleaning and lubrication for each stand type.

For New Century stands, we found that a reduction in the measured hand forces began after the first 30° of operation. This probably occurred because the New Century stand is designed so that it does not begin to move the switch points until after the first 30° of operation. Therefore, lubrication of the switch points is not expected to have much of an effect on hand forces until after the switch stand lever travels its first 30°. Notice that the average measured hand forces at the beginning of operation were 30 to 35 pounds. This is the weight of the switch stand lever handle. The largest reduction in hand force occurred at the end of operation. Here, measured hand forces fell from 31 lbs to 14 lbs on average, a statistically significant reduction of 56 percent.

For Racor stands, cleaning and lubrication did not have as large an effect in reducing the measured hand forces as it did for New Century stands. The effect was largest and statistically significant over the middle of stand operation, where the measured hand forces were 35% lower on average.

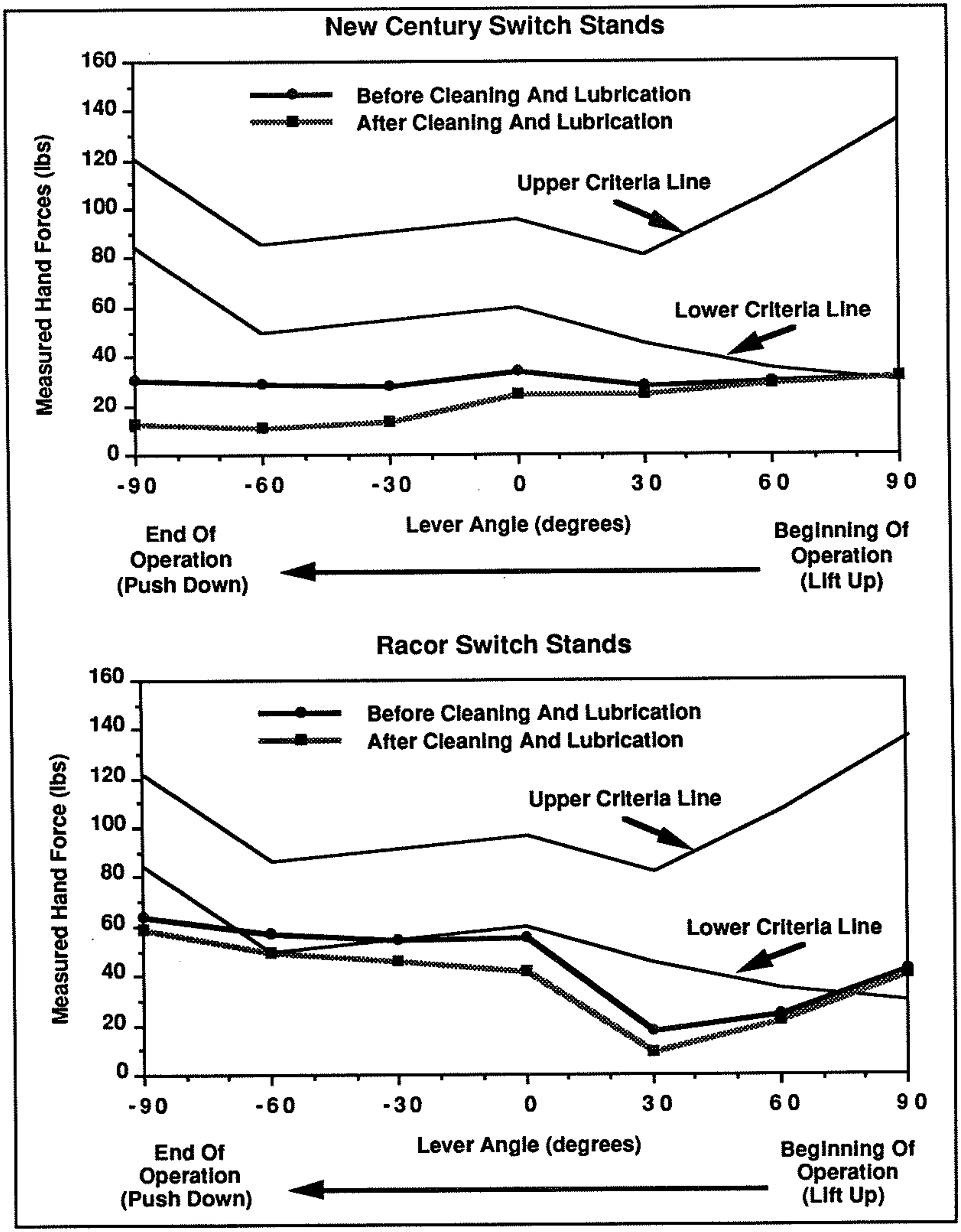



Figure 8.
Average Measured Hand Force By Switch Stand Lever Angle Before And After Cleaning And Lubrication

*The Effect of Connecting Rod Adjustment*

We performed a cursory evaluation of the effect of adjustment of the connecting rod. The length of the connecting rod can affect the contact force ("lock-out" force) between the switch point and the stock rail. Adjustment of the rod should not significantly affect the forces needed to move the switch stand lever from the beginning through the middle of its movement. We measured the hand forces before and immediately after a maintenance of way crew adjusted the connecting rod of one New Century switch stand. We selected a switch that was particularly difficult to "lock out" in order to see if adjustments of the connecting rod could effectively bring the hand forces near to the lower human performance criteria line in Figure 6.

Figure 9 shows that, as expected, adjustment of the connecting rod for this particular switch reduced the measured hand forces over the last part of operation. The measured hand force over the last 15° of operation was 191 lbs. before adjustment on average. After adjustment, the average measured hand force fell to 92 lbs. We only adjusted the connecting rod once. So, it is possible that additional adjustments might have reduced the measured hand forces further.

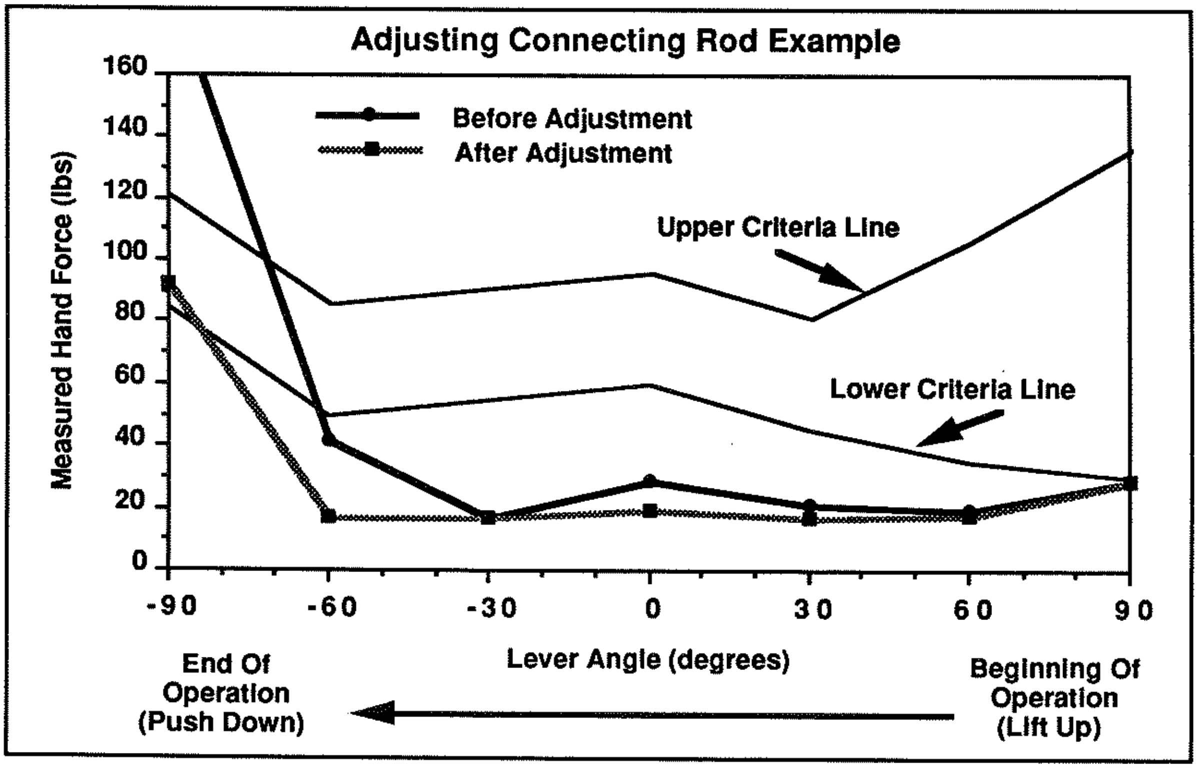



Figure 9.
The Average Measured Static Hand Forces By Switch Stand Lever Angle Before And After Adjustment Of The Connecting Rod

Further reduction of the hand forces at the end of switch stand lever movement may be possible through connecting rod adjustment. This depends on the requirements for contact force between the switch point and the stock rail. This required contact force may need to be more precisely defined so that switches may be adjusted for easier operation while not increasing the chances for derailment.

## 11.0 Analysis Of Some Switch Stand Design Issues

Our evaluation of the typical maintenance procedures used by railroads found that these **procedures** effectively lowered the forces needed to operate most of the switches we evaluated. On **average** we found that these forces were reduced to a level that was near or within the capability of most workers. But we found that for some individual switches it was difficult to reduce the hand forces to this level. In addition, our evaluation did not include a determination of how long these lower hand forces would remain in effect. This of course depends on many factors, including the maintenance **practices** (i.e. the frequency that typical maintenance procedures are performed) in place at individual yards as well as the amount of switching, weather conditions, and other factors.

It seems reasonable to expect that improvements in switch stand and/or switch design might give greater assurance that hand forces will remain at a lower level for a longer period of time. This in turn might reduce the required maintenance frequency necessary to keep hand forces at lower levels. Or it might be possible to improve the mechanical advantage and/or alter the handle weight of these switch stands so that the forces needed for their operation are even lower to begin with.

In this section of the report, we mathematically evaluate the possible effects of changes in two switch design parameters: the weight of the handle and the mechanical advantage provided by the switch stand lever. The goal of our analysis was to identify those combinations of handle weight and mechanical advantage that could increase our assurance that the hand forces needed to operate 95 percent of the switches that we evaluated would be near or within the capability of most workers (assuming they use smooth motions) .

Following our analysis, we present the findings from a field evaluation of prototype levers for the Racor 22 and New Century 50/51 tested by Conrail.

Our analysis included the following basic steps.

(1) We determined the load that must be moved by the switch stand. This load is defined as the force applied through the connecting rod to move the switch points (the connecting rod force). This is not an absolute number. It can and does vary from switch-to-switch. Given the lever weights and lever lengths of the switch stands we evaluated and knowing the

hand forces we measured from those same switch stands, we computed the loads that were moved, leaving the stand's mechanical advantage as an unknown. This provided us with a sampling of the connecting rod forces.

(2) Given the sample of the loads moved by the switch stand (the connecting rod forces) from Step 1, we systematically varied the mechanical advantage produced by alternative lever lengths using a simple static mathematical model of the task. We then computed the handle weight that allows a worker to generate 95%tile connecting rod forces while only applying hand forces equivalent to the lower human performance criteria line in Figure 6. We then repeated this step for the upper human performance criteria line.

(3) We repeated Steps 1 and 2 for two cases: (1) using measurements taken from switches some time prior to typical maintenance, and (2) using measurements taken from switches some time after typical maintenance. This step enabled us to describe a range of "acceptable" combinations of mechanical advantage and handle weight covering the possible range of conditions of current switches.

The analyses that follow have several limitations. First, the sample of switches we used to obtain a distribution of the forces needed to move switch connecting rods was small. It may or may not be representative of switches in general. Second, the human performance criteria lines, which are used in these analyses, have several limitations that were discussed earlier. Finally, the model of the task with which we performed our analyses ignores the inertial effects of lever motion.

Our analyses are probably affected by these limitations. Nevertheless, the following analyses provide a good illustration of a method for evaluation of simple switch stand design alternatives. And by weighing these caveats carefully, we feel that reasonable conclusions can be made. Details regarding the steps outlined above follow.

*Simple Static Model of The Task*

Figure 10 shows a free body diagram of the forces (**F**) and load moment (**M**) acting upon the switch stand lever while being operated. This model assumes the task to be a series of static exertions. Thus we must also assume that the inertial effects created by the weight of the handle are minimal.

The diagram illustrates three forces and a moment. One is the force applied by the worker's hand(s) to the switch stand lever handle, $F_{hand(s)}$. A second force is applied by the stand at the switch stand lever axis (pivot); the two components of the force are shown. The gravitational force of the lever is shown as $F_{weight}$. This force includes the weight of the "arm" portion of the lever and the "handle." The total weight of the lever, handle and arm, act through the lever's center of gravity. The moment acting upon the lever is the resistance due to the switch rails, $M_{rails}$. (This also includes any resistance attributable to the switch stand mechanism).

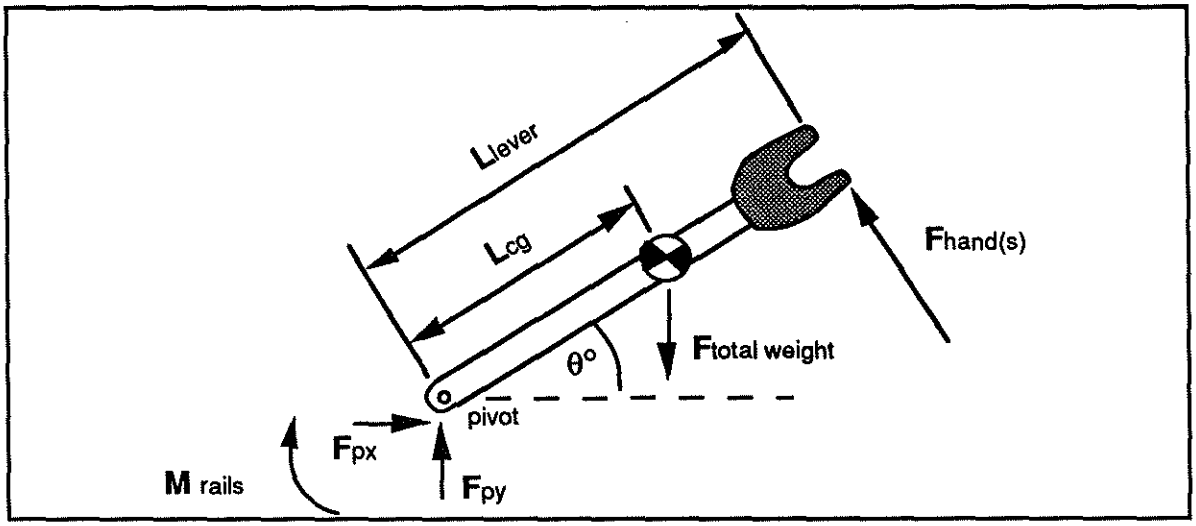



Figure 10.
Free Body Diagram Of Forces And Moments Acting On The Lever

Equation (1.A) represents the relation between the forces and moment necessary to achieve static equilibrium of moments about the axis of the lever or pivot.

$$F_{hands} = \frac{M_{rails}}{L_{lever}} + \frac{\left[F_{total\ weight} \cdot \cos(\theta) \cdot L_{cg}\right]}{L_{lever}} \qquad (1.A)$$

$M_{rails}$ = Resistance attributed to the switch rails (inch-lbs)
$F_{hands}$ = Force applied to the lever handle by the hand(s) of the worker (lbs)
$F_{total\ weight}$ = Gravitational force of the lever mass (lbs). This includes the weight of the handle and the switch stand lever.
$L_{lever}$ = Length of the switch stand's lever (inches)
$L_{cg}$ = the distance from the lever axis to the center of gravity of the entire lever—the switch stand lever and handle (inches).
$\theta$ = Theta. The included angle between the lever and horizontal right of the axis (degrees). Note: this angle is dependent on the lever angle as defined earlier in this report ($\theta$ = 90° - lever angle).

The moment due to the resistance of the switch rails acting at the pivot can be transformed to a force acting at the end of the switch stand lever. Consequently, Equation (1.A) can be reduced to Equation (1.B).

$$F_{hands} = F_{rails} + F_{total\ weight} \cdot \cos(\theta) \cdot \left(\frac{L_{cg}}{L_{lever}}\right) \qquad (1.B)$$

$F_{rails}$ = Resistance attributed to the switch rails (lbs) acting at the handle in the opposite direction of $F_{hand(s)}$

*Step 1: Calculating The Connecting Rod Forces Required to Move The Switch Rails*

The resistance due to the switch rails at the handle can be translated to the resistance at the connecting rod using the mechanical advantage of the stand. Equation (2) illustrates.

$$F_{rails} = \frac{F_{rod}}{MA} \qquad (2)$$

$F_{rod}$ = Resistance force at the connecting rod attributed to the switch rails (lbs)

MA = The mechanical advantage of the switch stand. The relationship between the force applied to the end of the lever and the force transmitted through the connecting rod. So for every pound of hand force applied to the lever handle in the tangential direction of lever movement, (MA) pounds of force is applied through the connecting rod that moves the switch rails.

We leave the mechanical advantage unknown through our analysis since our definition may differ with switch stand manufactures. Further, the mechanical advantage for some switch stand designs is uncertain.

The mechanical advantages for the stands we evaluate here do vary with the lever angle. This is due to the change in the angle between the stand's crank and connecting rod as the lever angle changes, among other factors. See Part 1 of Appendix C for further explanation.

Now, Equation (2) can be substituted into Equation (1.B). This allows us to solve for the force at the connecting rod that is required to move the switch rails given the other known variables.

$$F_{hands} = \left(\frac{F_{rod}}{MA}\right) + F_{total\ weight} \cdot \cos(\theta) \cdot \left(\frac{L_{cg}}{L_{lever}}\right) \qquad (3)$$

solving for $F_{rod}$ we get,

$$F_{rod} = \left[ F_{hands} - F_{total\ weight} \cdot \cos(\theta) \cdot \left( \frac{L_{cg}}{L_{lever}} \right) \right] \cdot M\,A \qquad (4)$$

Appendix C, Part 2 explains how $L_{cg}$ is calculated. By substituting the equation for $L_{cg}$ from Appendix C into Equation (4) we get,

$$F_{rod} = \left[ F_{hands} - \cos(\theta) \cdot \frac{\left[ \left( L_{arm\text{-}cg} \cdot F_{arm\ weight} \right) + \left( L_{handle\text{-}cg} \cdot F_{handle\ weight} \right) \right]}{L_{lever}} \right] \cdot M\,A \qquad (5)$$

$L_{arm\text{-}cg}$ = the distance from the lever axis to the center of gravity of the switch stand lever in inches (not including the handle).

$L_{handle\text{-}cg}$ = the distance from the lever axis to the center of gravity of the handle in inches (not including the arm).

$F_{arm\ weight}$ = the weight of the switch stand lever in pounds (not including the handle).

$F_{handle\ weight}$ = the weight of the handle in pounds (not including the switch stand lever).

We calculated the connecting rod forces required to move the switch points at each sector of lever movement for 77 switches—39 New Century stands and 38 Racor stands—using Equation (5). The lever weights were set to the current New Century and Racor specifications (the mechanical advantages were set as unknown). And the hand forces $F_{hand(s)}$ were set to the 95th percentile value hand forces we measured for each sector (i.e. only 5% of the switch stands we measured had hand forces greater than these values). This ensures (within the stated limitations of this analysis) that a worker using a switch stand that incorporates any design modifications we may identify can operate (assuming the use of smooth motions) most (95%) of the switches we evaluated—without applying hand forces greater than the lower or upper hand force criteria lines in Figure 6.

*Steps 2 and 3: Evaluating Mechanical Advantage And Handle Weight Alternatives*

Using the connecting rod forces required to move the switch points calculated above, we again solved Equation (5). We set the hand forces $F_{hand(s)}$ to operate each stand equal to the human performance criteria lines from Figure 6. Then Equation (5) was solved for various combinations of mechanical advantage multipliers (multiples of the current, unknown mechanical advantage) and handle weights for each sector of switch stand lever movement. The equation produces a line for each sector.

Each point on the lines represents a combination of handle weight and mechanical advantage that satisfies Equation (5). Values that lie within the region defined by the most restrictive lines (sectors) satisfy Equation (5) for each sector. This region defines the range of possible combinations of handle weight and mechanical advantage for that switch stand type that will satisfy the human performance criteria lines in Figure 6. We call this the design region. (See Appendix C: Part 3 for details regarding the equations used and assumptions made in these design region analyses).

Figure 11 shows the design regions for the New Century models 50 and 51 switch stand type for conditions after typical maintenance (top) and prior to typical maintenance of the switches (bottom). Design Region 1 defines the combinations of mechanical advantage multiplier and handle weight for the operation of switches that satisfy the upper human performance criteria line. Design Region 2 defines the combinations for the operation of switches that satisfy the lower human performance criteria line. Altogether, four regions were defined for each switch stand type:

- a region that satisfies the upper human performance criteria line for switches after typical maintenance procedures,
- a region that satisfies the lower human performance criteria line for switches after typical maintenance procedures,
- a region that satisfies the upper human performance criteria line for switches prior to typical maintenance procedures,
- a region that satisfies the lower human performance criteria line for switches prior to typical maintenance procedures,

The mechanical advantage multiplier can be interpreted as follows: 1.0 represents the current, but unknown, mechanical advantage. A multiplier of 1.5 represents a lever length increase of 50% and thus a mechanical advantage increase of 50%, and so on.

*Trends and Specific Findings for the New Century Stand (Models 50 and 51):*

**Note: The findings presented below are subject to the limitations of this analysis and of this report that were stated earlier and are not, therefore, conclusive.**

For the design regions in both the top and bottom graphics of Figure 11, the top boundaries are restricted by one or more of the first 3 sectors of switch operation (first 90° of operation). Handle weights that satisfy these boundaries gradually decrease as the mechanical advantage multiplier increases. This occurs because as the lever becomes longer, an increase in the mechanical advantage multiplier, its total weight—handle and arm—increases. This is a critical issue since no matter how long the lever is, nor how great its mechanical advantage, it still must be lifted at the beginning of operation. For the New Century stand, the weight of the lever is all that must be overcome for approximately the first 30° of operation, due to its design. The stand begins to move the switch rails afterwards.

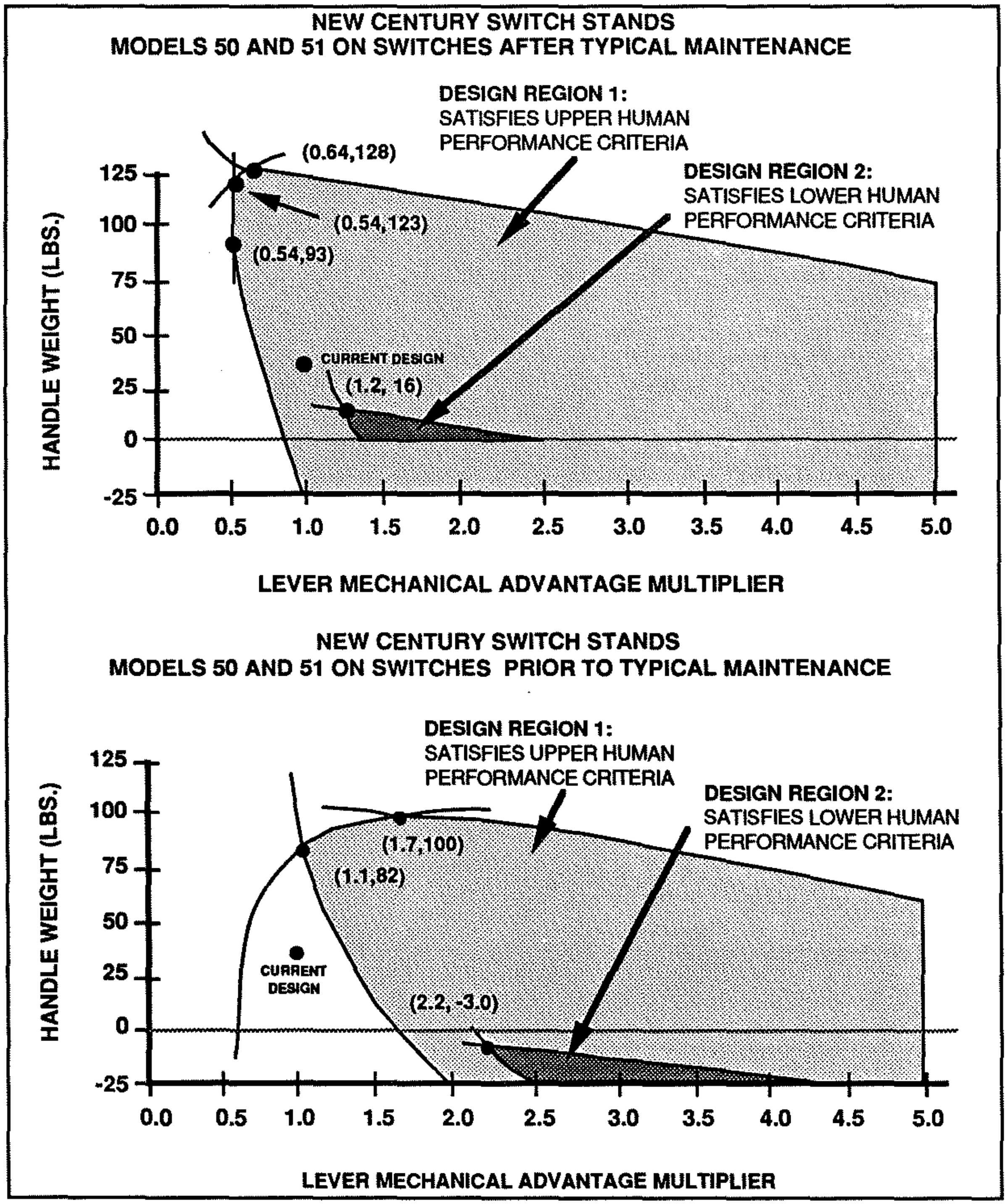



Figure 11.
Combinations Of Handle Weights And Mechanical Advantage Multipliers That Satisfy Human Performance Criteria For New Century Switch Stands

The boundaries on the left are defined by one or more of the last 3 sectors of operation (the last 90° or operation). Over the last 90° of operation of the switch stand, handle weight helps the lever movement, versus impeding movement over the first 90° of lever operation. As handle weight increases, the hand force necessary to move the lever falls.

For each of the left side design region boundaries in both the top and bottom figures, handle weight is very sensitive to changes in the mechanical advantage multiplier. This can be explained by remembering that the resistance moment due to the switch rails must be overcome by the moment produced by the lever and worker. This moment can be increased by increasing the handle weight or the lever's mechanical advantage (for a fixed hand force). For example, to double the moment, you can either double the handle weight or double the mechanical advantage. Thus to produce an equivalent moment, if the mechanical advantage multiplier is cut in half, the handle weight must be approximately doubled. (It is not exactly doubled because the center of gravity of the lever relative to the lever's length changes with lever length).

The large separation between the upper boundaries of Design Region 1 and 2 occur because the difference between the lower and upper human performance criteria lines are large at the beginning of operation (30 lbs vs. 135 lbs). The difference between the left boundaries is not as large since the difference between the lower and upper criteria lines are smaller at this point in lever movement (85 lbs vs. 120 lbs). The specific equations that define each boundary are provided in Appendix C.

The lower graphic in Figure 11 shows how both Design Regions 1 and 2 shrink for switches prior to typical maintenance vs. switches after typical maintenance. This occurs because the connecting rod forces that the switch stand must overcome (applying the same hand forces) are larger.

For switches after typical maintenance, the current New Century design lies between Design Region 1 and 2. The top of Figure 11 shows that the current design satisfies the upper human performance criteria lines under these maintenance conditions. It also shows that a reduction of handle weight to about 16 lbs and a mechanical advantage 20% larger than the current value might satisfy the lower human performance criteria line for most (95%) of the switches we evaluated.

The bottom figure illustrates that the current design lies outside Design Regions 1 and 2. The current design does not satisfy the left boundary of Design Region 1. But it does satisfy the top boundary. This means that the current design meets Design Region 1's restriction for the beginning and middle of operation, but not at the end of operation. Design Region 1 could be met by increasing the length of the lever 40 to 50%.

To satisfy the lower human performance criteria (Design Region 2), the length of the lever would have to be more than doubled. And the weight of the lever handle would have to be eliminated. However, this is not recommended. One, increasing the length of the lever this much would probably create too long of a lever for shorter people to operate in the middle of lever movement (i.e. the human performance criteria lines would fall for such a design). Two, some mass at the end of the lever allows the worker to more easily generate inertial forces that might assist the lever through difficult portions of lever movement.

So, if an alternative lever design where to be considered, a combination of a longer lever (about 36 inches) with a slightly lighter handle (15 to 20 lbs) might be best. Such a design would be within Design Region 1 and closer to Design Region 2 for switches prior to typical maintenance. And it would practically be within Design Region 2 for switches after typical maintenance. This lever would still provide some mass at the end of the lever to assist in generating inertial forces when needed. And such a lever length would increase the stands mechanical advantage without requiring significantly lower worker capabilities—human performance criteria lines.

Note: this analysis does not account for the inertial effects of lever movement. A heavier handle may be preferred to assist in the middle and end of lever movement. However, if the lever was jerked during the beginning of movement, the top boundaries of the design regions in Figure 11 (and Figure 12) would be more restrictive. Thus a 20 lb. or so handle for the New Century stand may be preferred as long as it is not "jerked" at the beginning of movement.

*Trends and Specific Findings for the Racor Stand (Model 22):*

**Note: The findings presented below are subject to the limitations of this analysis and of this report that were stated earlier and are not, therefore, conclusive.**

Figure 12 illustrates our analyses of the Racor 22 switch stand. The Design Region trends for the Racor switch stand design are similar to those of the New Century design, except for 2 points. One the left boundary of Design Region 1 for switches prior to typical maintenance is defined by the middle sector of operation (when the lever is upright). The boundary is a vertical line. It illustrates that handle weight has no effect on the mechanical advantage required by the stand to achieve our design goals when the lever is upright. This is intuitive because the handle's weight is being supported entirely by the lever at this point, not by the individual operating the stand.

Two, both design regions that satisfy the lower hand force criteria lines only include negative handle weights. This means that even a lever without a handle would not satisfy Design Region 2, regardless of the lever's length, and thus its mechanical advantage. This occurs because the Racor 22 is designed to begin moving the switch rails immediately as the lever is lifted. So, unlike the New Century design, when lifting the Racor handle, the worker must overcome the weight of the lever and resistance due to the switch rails.

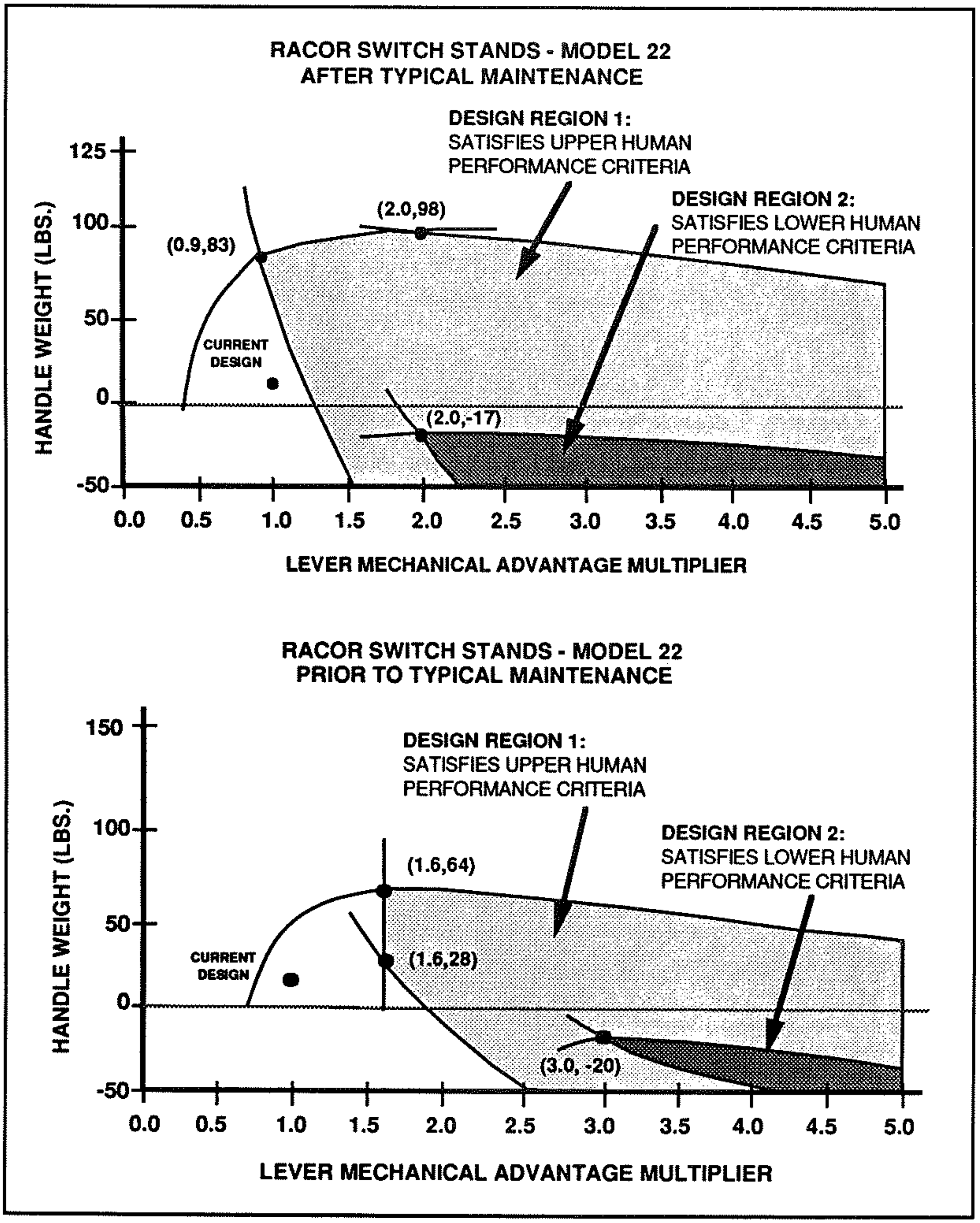



Figure 12. Combinations Of Handle Weights And Mechanical Advantages That Satisfy Human Performance Criteria For Racor Switch Stands

The current Racor 22 design (mechanical advantage multiplier = 1.0, handle weight = 10 or 17 lbs.) lies outside Design Regions 1 and 2 for switches after typical maintenance as well as switches prior to typical maintenance. The current lever design can not be altered to satisfy the lower human performance criteria lines without changing the material used for the lever (and thus the weight for a given length). But increasing its lever length would certainly be an improvement.

For switches after typical maintenance, Design Region 1 could be satisfied by increasing the stand's mechanical advantage about 25%—keeping the handle weight the same. An increase of 50-60% in the mechanical advantage would bring the design even closer to Design Region 2.

For switches prior to typical maintenance, Design Region 1 could be satisfied by increasing the lever length about 60% and increasing the handle weight to about 28 lbs This could allow workers to operate 95% of the stands we evaluated without exerting hand forces that exceed the upper human performance criteria line. Increasing the handle's weight may not be recommended since it increases the distance between the current design and the top boundary of Design Region 2, even though it brings the stand within Design Region 1 (i.e. in this situation, increasing the handle weight may reduce the risk of injury at the end of operation but increase the risk at the beginning of operation).

So, if an alternative design were to be considered, a combination of a longer lever (about 36 inches) with the same handle weight as the current design might be best. This is shorter than a 50-60% increase in lever length. But a 50-60% increase would probably reduce the human performance criteria lines and thus shrink the design regions. This design would bring the stand within Design Region 1 for switches after typical maintenance and practically within the region for switches prior to typical maintenance. And it would be closer to Design Region 2 for both maintenance conditions.

> Note: The human performance criteria for longer levers (beyond 36 inches) may differ from the values presented in Figure 6. This may occur because the postures (i.e. worker methods) required to operate a longer lever may differ from those that were used to develop the human performance criteria in Figure 6. But the human performance criteria would probably only differ over the middle of switch operation. And for lever lengths within 24 to 36 inches, the criteria should not differ significantly. Thus, any alternative design beyond approximately 36 inches would require a complete ergonomic analysis similar to the one presented in this report for current designs. But the design regions presented above should suffice for alternative designs between 24 and 36 inches.

In summary, it must be remembered that these design regions are not exact. They are only estimates based on the limited sample of switches we measured and the limited number of operating methods we evaluated. As mentioned earlier, there is much room for error. This section simply illustrates one way to investigate some of the design aspects of these switch stands.

Furthermore, we only investigated the effects of increasing mechanical advantage by increasing lever length. We did not investigate increasing mechanical advantage by altering the internal mechanisms of the switch stands. Our findings suggest that increasing lever length may not be enough to bring the Racor and New Century stands within Design Region 2 for switches prior to typical maintenance. This appears to be true for Racor stands on switches after typical maintenance as well. In these cases, it may be necessary to increase the internal mechanical advantage of the switch stands.

Furthermore, the strength of the materials used in longer levers should be examined to ensure that the lever and stand are strong enough to withstand field operating conditions. The American Railway Engineering Association (1989) addresses this issue stating, "the physical properties of a completed stand shall be such that the application of a force of 650 lbs at the center of the hand hold shall not stress any of the material in the stand to its yield point."

Lastly, alternative switch stand design prototypes should be evaluated under real operating conditions to verify their capability to reduce the forces needed to operate them. Results from such an evaluation follow.

## 12.0 Field Evaluation Of Alternative Designs

The Safety Department at Conrail evaluated alternative switch stand lever designs for the Racor 22 and New Century 50/51 switch stands. For the Racor 22, the alternative lever was 36 inches long, as opposed to the current design of 26 inches. And the handle weighed 7 lbs on some levers and 10 lbs on others. The handle weight for current 26 inch levers is 10 lbs. For the New Century 50/51, the alternative switch stand lever was 36 inches long with a handle weight of 28 lbs. The current design has a lever that is 24 inches long with a handle weight of 35 lbs They made comparisons of hand force measurements (using smooth motions) taken before and after replacement of the current switch stand levers on 6 Racor switch stands and 5 New Century switch stands.

The increase in the Racor 22's lever length increased the stand's mechanical advantage by 38%. But the longer lever arm added about 10 pounds to the total weight of the lever. Thus we would expect that the measured hand forces would be reduced less than 38% at the beginning of lever movement, and more than 38% at the end where the added lever weight helps the worker.

Figure 13 compares the hand forces needed (assuming smooth motions) to operate the two different Racor 22 levers. These hand forces were reduced by 19% at the beginning of lever movement. The reduction was 45% at the middle of lever operation and 46% at the end.

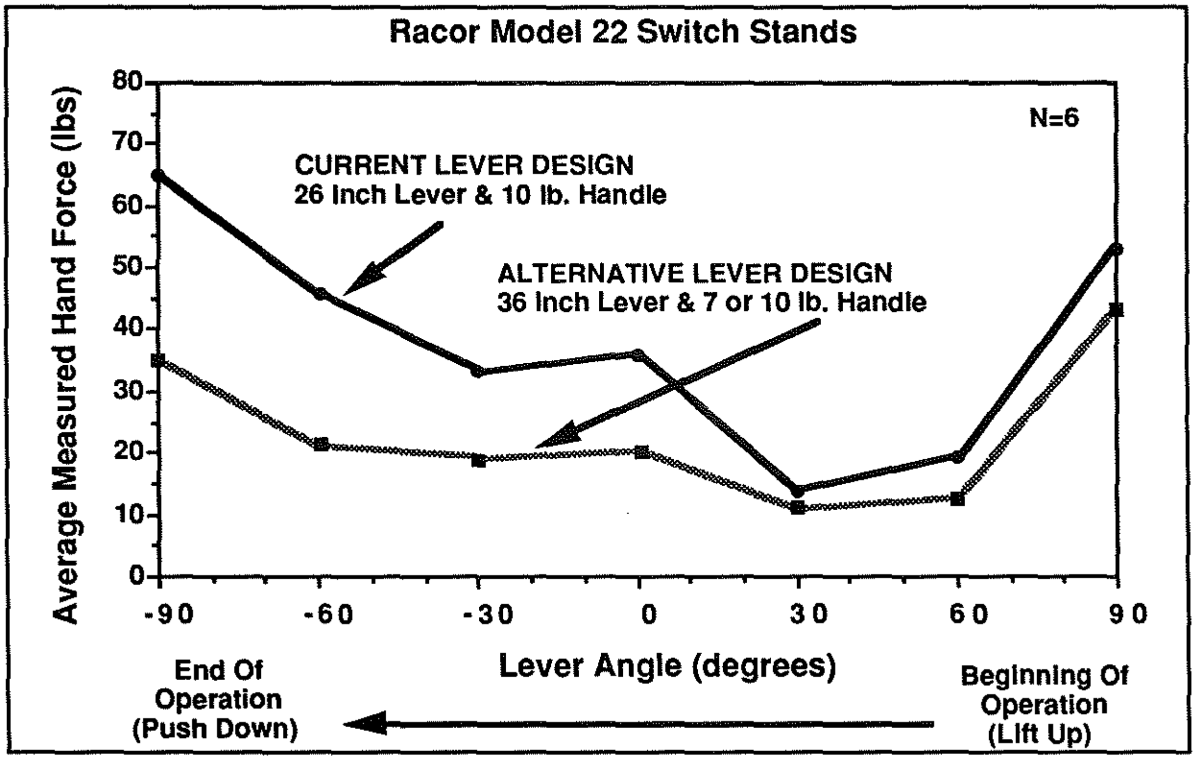



Figure 13 Effect Of Switch Stand Lever Design Changes On Measured Hand Forces For Racor Model 22 Switch Stands

For New Century stands, the longer lever increased the stand's mechanical advantage by 50%. But the longer lever arm added about 5 pounds to the total weight of the lever. Thus we would expect that the hand forces would be reduced less than 50% at the beginning of lever movement, and more than 50% at the end where the added lever weight helps the worker.

Figure 14 compares the hand forces needed (assuming smooth motions) to operate the two different New Century 50/51 levers. The hand forces were reduced by 23% at the beginning of lever movement. The reduction was 48% at the middle of lever operation and 64% before the switches were "locked out." However, the hand forces increased at the "lock out" point by about 23%. **This was not due to the new lever.** After the new levers were installed, the stands/switches were adjusted so that the "lock out" force was approximately at or below the lower hand force guideline of 85 lbs. The hand forces needed to operate the stand were then measured afterwards. So the results at the "lock out" point could easily be higher with the new lever due to the readjustment of the switch and stand. Thus the results at the "lock out" point of operation should not be considered to be an evaluation of the effectiveness of longer levers.

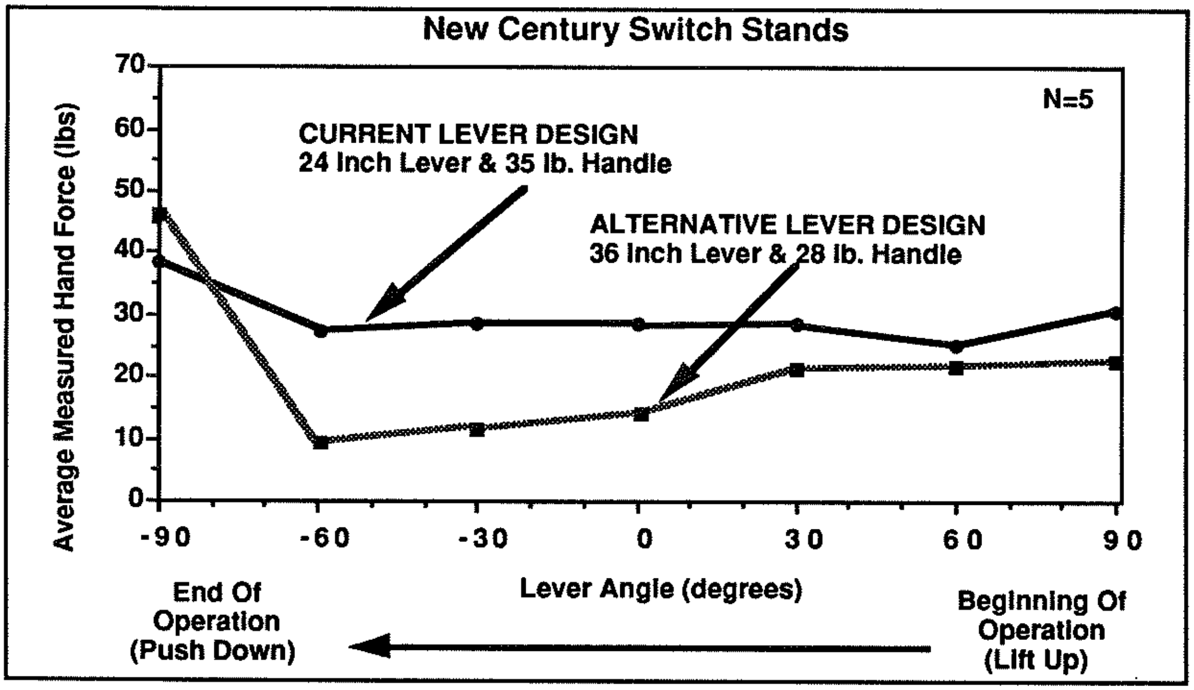



Figure 14 Effect Of Switch Stand Lever Design Changes On Measured Hand Forces For New Century Model 50/51 Switch Stands

These results seem to follow our expectations. They show that a longer lever arm can reduce hand force requirements throughout the lever's motion. But the reduction is not as large at the beginning as at the end due to the increased weight of the lever, due to the longer lever arm. No noticeable difference was seen between the 7 and 10 pound handles for the Racor stands. This is expected since the accuracy of the measurement gauge was only within 5 pounds. The heavier Racor handle, however, appeared to operate more "smoothly."

For New Century stands, a slightly lighter handle, such as 20 lbs. mentioned in the previous section, could offset the increase in total lever weight (due to the longer lever length) and reduce needed hand forces further.

## 13.0 Summary

This research provides the industry with several tools that may be useful in reducing the number of employee injuries associated with the operation of ground level hand switch stands.

(1) We found that some of the method categories we evaluated were better than others.

(2) We developed human performance criteria for switch stand evaluation and design.

(3) We developed a simple, repeatable, and accurate way to measure the hand forces needed by workers to operate individual switch stands—assuming the worker uses smooth motions and applies force at the switch stand handle and in a direction orthogonal to the switch stand lever.

(4) We showed that typical maintenance procedures seem to be very effective (on average) at reducing the forces.

(5) We demonstrated how our human performance criteria could be used to identify and evaluate alternative designs for switch stand levers.

## 14.0 References


American Railway Engineering Association (1989). Portfolio of Trackwork Plans: Switch Stands and Appurtenances (Plan #251-64). The Author, Washington.

Chaffin, D.B., Kerk, C.J., Woolley, C., Foulke, J. (1988). Ergonomic investigation of selected railroad yardmen activities (Technical report under contract with the Association of American Railroads. Contract No. ESD-87-024). The University of Michigan Center for Ergonomics: Ann Arbor.

Federal Railroad Administration, Department of Transportation (1987). Code of Federal Regulations Title 49, Part 236, Section 334. Government Printing Office: Washington.

Kuciemba, S.R., Page, G.B., and Kerk, C.J. (1988). An ergonomic investigation of railroad yard workers. In F. Aghazadeh (Ed.) Trends in Ergonomics/Human Factors V, (pp. 1061-1068). Elsevier Science Publishers B.V. (North-Holland): Amsterdam.

McMahan, P.B. (1988). Strength testing may be an effective placement tool for the railroad industry. In F. Aghazadeh (Ed.) Trends in Ergonomics/Human Factors V, (pp. 787-794). Elsevier Science Publishers B.V. (North-Holland): Amsterdam

McMahan, P.B., Page, G.P., & Kuciemba, S.R. (1987). Analysis of FRA casualty data: 1979-1986. Washington, DC: Association of American Railroads, Department of Safety Research.

National Institute for Occupational Safety and Health. (1981). Work practices guide for manual lifting (DHHS (NIOSH) Publication No. 81-122). Akron, Ohio: American Industrial Hygiene Association.

## Glossary

### Hand Force, Forces Needed

*Hand force* refers to the force of the workers hands on the switch stand lever, measured by smoothly pulling or pushing on a gauge attached to the lever handle at a point where the worker's hands would be located and in a direction perpendicular to the switch stand lever. The magnitude of the hand force that is needed to move the lever in this manner (i.e. quasi-static) is referred to, in this report, as the *needed hand force.* And the direction of the needed hand force, in this report, is orthogonal to the switch stand lever.

Throughout this report we made the simplifying assumption that, in order to operate the switch stands we evaluated, workers must apply forces of the same magnitude and in the same direction as our hand force (defined above) measurements were made by pulling or pushing with their hands. Further, we assume that smooth controlled movements are made so that little or no inertial effects are present. We refer to these forces as the *hand forces needed* to operate the switch.

### Strength Needed

The strength a person needs to generate the hand forces needed to perform a task. In the context of this research, the hand forces needed to move the switch stand lever are assumed to be created by muscle contractions and smooth motions. The only way, in this context, to generate larger hand forces is through greater muscle strength.

# Appendix A
# Switch Stand and Switch Evaluation Procedure and Data Sheet

## (1) *Necessary Equipment*

The evaluation procedure requires the use of a good quality push/pull force gauge with dual handles and a capacity of **at least** 150 to 200 lbs. The gauge should have 2.5 or 5 pound graduations or increments. You also need about one foot of sturdy rope with a tensile strength of at least 800 lbs. (nylon rope with a diameter of at least 3/16 of an inch should meet this requirement ) and a tape measure.

Two sources for such push/pull hand force gauges are:

Wagner Instruments
P.O. Box 1217
Greenwich, CT 06836
(203) 869-9681

Nels Jorgenson & Co.
20400 Nine Mile Road
P.O Box 347
St. Clair Shores, MI 48080-0347
(313) 774-6600

There may be other retailers that offer push/pull hand force gauges.

## (2) *Set up Equipment*

The first two force measurements are made by pulling the gauge. To do so, loop the piece of rope around the hook attachment on the force gauge and around the lever arm handle. For New Century stands, locate the rope at the beginning of the curve in the lever arm handle (2 to 3 inches from the end of the handle as shown in Figure A.1). For Racor stands, loop the rope through the handle that extends from the "ball."

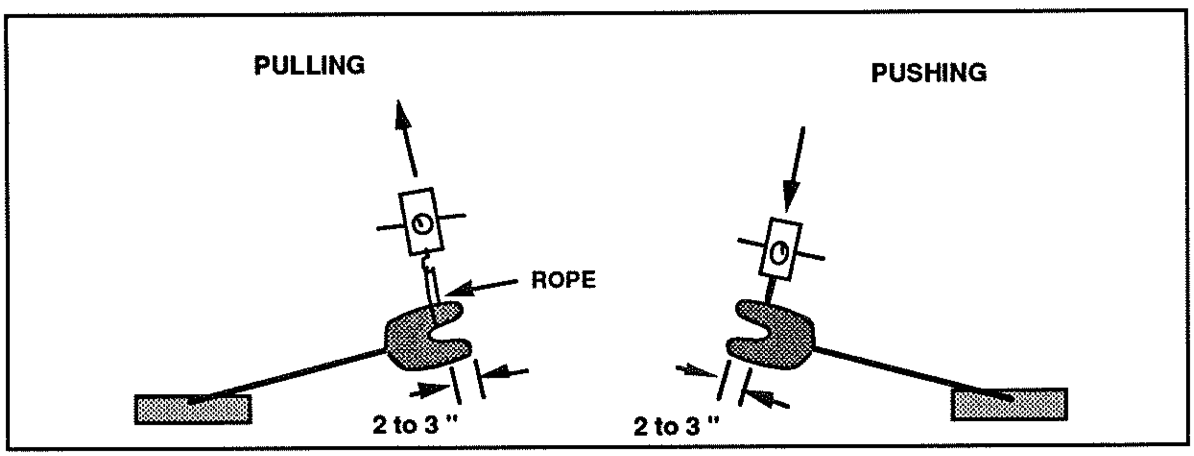



Figure A.1
Location and orientation of the push/pull gauge on the New Century stand's lever arm handle when pulling and pushing the hand force gauge.

The last measurement is made by pushing with the gauge. This can be done by removing the rope and using the wedge or point attachment at the end of the gauge. For New Century stands, place the point or wedge of the gauge 2 to 3 inches from the end of the handle as shown in Figure A.1. Often, you may be able to place the attachment point in one of the letters stamped on the handle. This helps keep the gauge from slipping. For Racor stands, place the point or wedge on the handle that extends from the "ball."

The human performance criteria correspond with measurements made at the locations on the handle described above. If you measure the forces to operate the switch stand lever at any other location, you will not be able to compare them to the guidelines. Any special attachments made to assist in static hand force measurement should still meet these location requirements.

Note: Use extreme care to avoid loosing balance and falling while making measurements. Be extremely careful that any attachment you may use to connect the force gauge to the switch stand handle does not slip off while you are applying force to the gauge.

*(3) Make Measurements*

Static hand force measurements should be made by pushing or pulling the hand force gauge in a slow and steady fashion. If the force required to perform the test appears to be too great for the tester, then two people should operate the force gauge. Some specific recommendations are as follows:

(A) Pull/push the gauge in a direction that is perpendicular to the lever arm and in the direction of motion.

(B) **Stop measuring if the measured force exceeds 150 lbs.** Further measurements are not necessary if you exceed this value. And you may increase your risk of slips/falls and musculoskeletal injuries when applying excessive forces to the handle.

(C) Peak forces should be read from 3 approximate sectors in the lever arm's 180° range-of-motion (see Figure A.2):

- first 15° of operation (**Lift Up**)
- middle 30° of operation (**Middle of Operation**)
- last 15° of operation (**Push Down**).

You can record measurements on the data sheet provided at the end of this Appendix

(D) Pull/push the gauge steadily through each zone without stopping.

(E) Measure and record the forces in both operating directions: right to left and left to right.

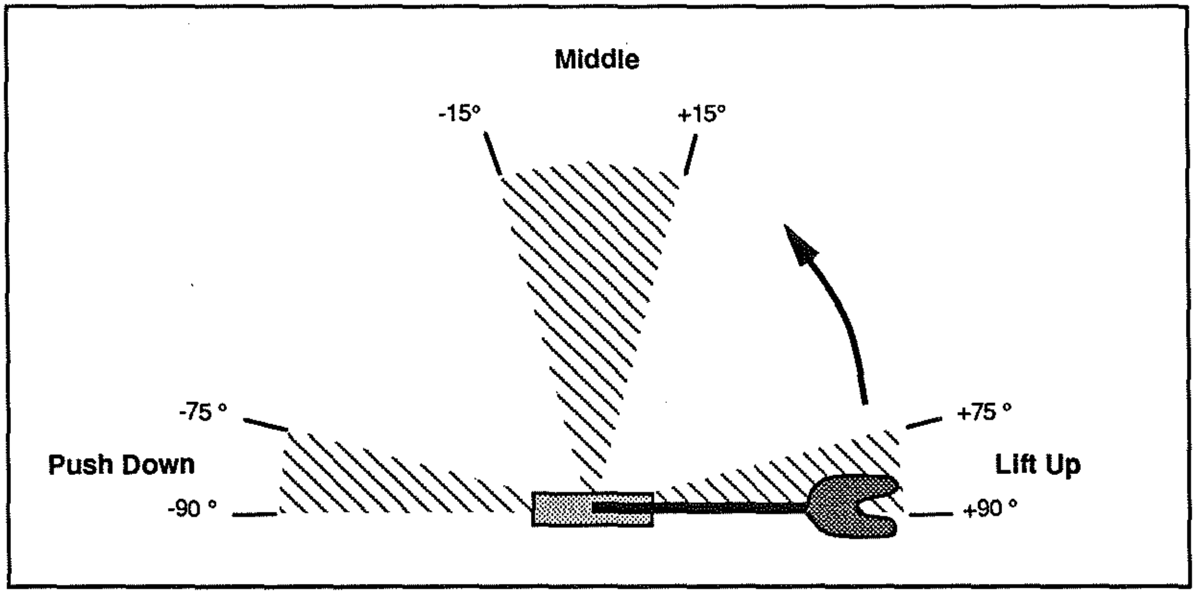



Figure A.2
The Angle Sectors Where The Peak Forces
Should Be Measured And Recorded.

(F) Make at least 2 sets of measurements in each direction. When learning this procedure, make three or more measurements in each direction until you achieve some consistency among the measurements.

*(4) Compare Measurements To Human Performance Criteria*

After the measurements have been made, average them for each of the 3 sectors for each operating direction. Then compare these 6 averages with the human performance criteria for those three angle sectors. Both the upper and lower guidelines are provided on the data sheet for your reference. These values are taken from the human performance criteria presented in Figure A.3 below.

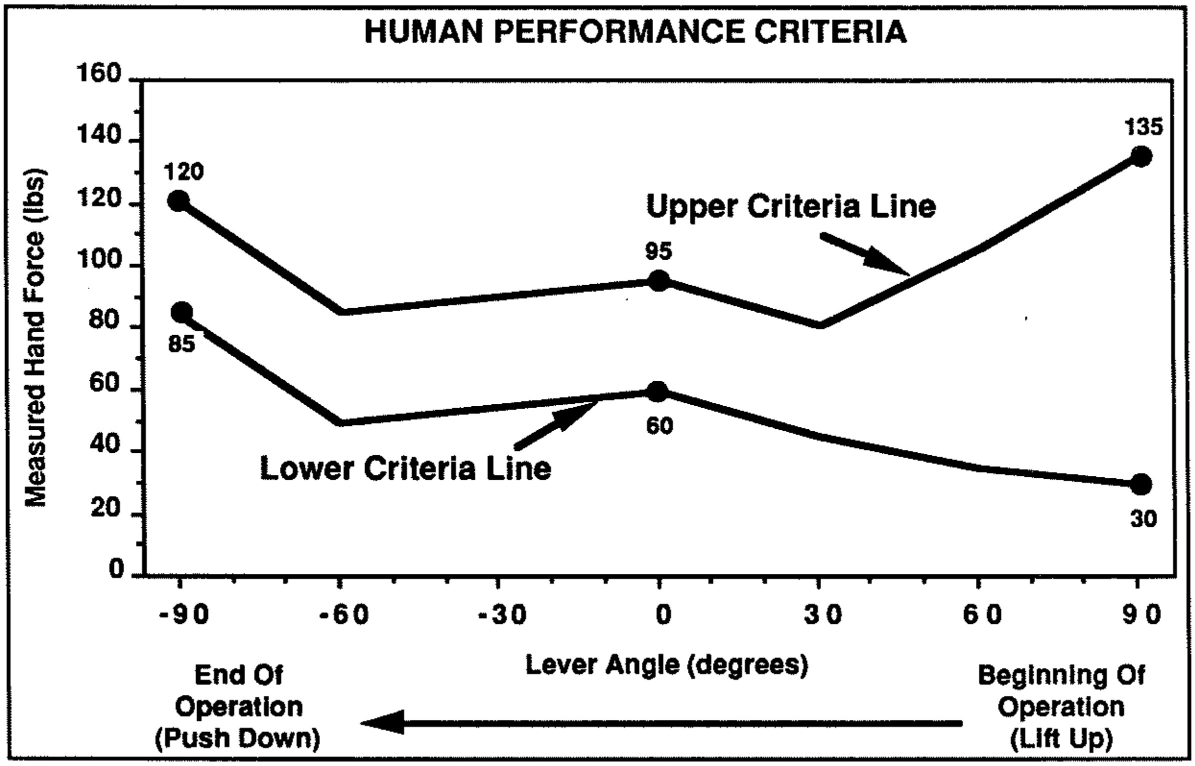


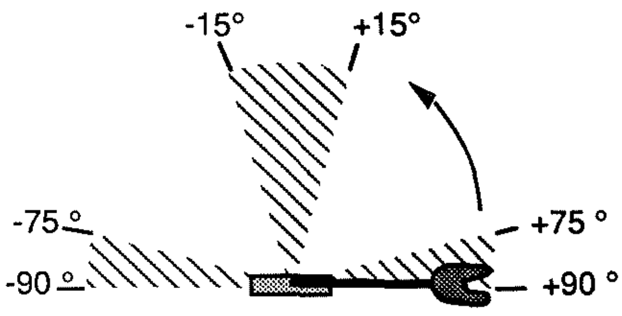

Figure A.3
Human Performance Criteria For Switch Stand Evaluation And Design

# Data Recording Sheet

Date: ____________________ Stand Type: ____________________

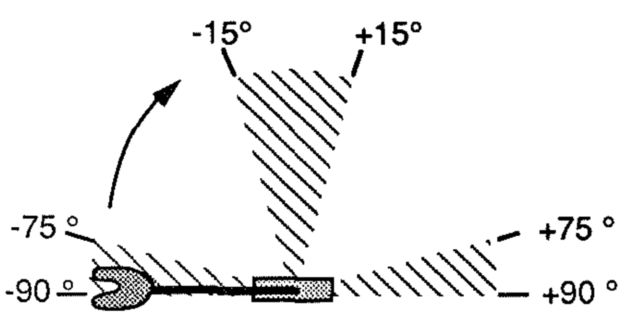
Yard: ____________________ Stand Number: ____________________

## RIGHT to LEFT Operation




| | Trial Number 1 | 2 | 3 | Human Performance Criteria Lower | Upper |
|---|---|---|---|---|---|
| Lift Up | | | | 30 | 135 |
| *Average* | | | | | |
| Middle | | | | 60 | 95 |
| *Average* | | | | | |
| Push Down | | | | 85 | 120 |
| *Average* | | | | Lower | Upper |

## LEFT to RIGHT Operation




| | Trial Number 1 | 2 | 3 | Human Performance Criteria Lower | Upper |
|---|---|---|---|---|---|
| Lift Up | | | | 30 | 135 |
| *Average* | | | | | |
| Middle | | | | 60 | 95 |
| *Average* | | | | | |
| Push Down | | | | 85 | 120 |
| *Average* | | | | Lower | Upper |

# Appendix B
# Summary Of The NIOSH Work Practices Guide For Manual Lifting

The National Institute for Occupational Safety and Health (NIOSH) developed a guideline for the design and evaluation of manual lifting tasks. It represents the first comprehensive approach to control injuries from over-exertion. Such injuries include low-back pain, localized muscle fatigue, and whole-body fatigue. Lifting limits set by this guideline are based on epidemiological, biomechanical, physiological, and psychophysical criteria. A complete description of the assumptions and basis of the lifting guide can be found in the original NIOSH report (NIOSH, 1981).

The NIOSH guideline is not intended for use in evaluating all types of manual materials handling tasks. It is intended to apply to smooth, two-handed, symmetric lifting directly in front of the body (the sagittal plane). Unrestricted lifting posture, good couplings (handles, shoes, floor surface), and favorable ambient environments are also assumed.

The NIOSH lifting guide is based on an equation that considers the following six lifting task variables (refer to Figure B1):

- Object Weight
- Horizontal Location Of Hands At Lift Origin
- Vertical Location Of Hands At Lift Origin
- Vertical Travel Distance Of The Hands At Lift Destination
- Lifting Frequency
- Duration Or Period Of The Lifting Task

These lifting task variables are used in the NIOSH lifting guide to compute an "Action Limit" (AL) and a "Maximum Permissible Limit" (MPL). According to NIOSH, lifting loads that are at or below the AL present a nominal risk of injury to most workers. Loads at or above the MPL present an unacceptable risk to nearly all workers. The AL and MPL are computed as follows:

$$AL = 90\ [6/H]\ [1 - .01|V-30|]\ [.7 + 3/D]\ [1 - F/F_{max}]$$

$$= 90\ [HF]\ [VF]\ [DF]\ [FF]$$

$$MPL = 3[AL]$$

where:

AL = the Action Limit in pounds.

MPL = the Maximum Permissible Limit in pounds.

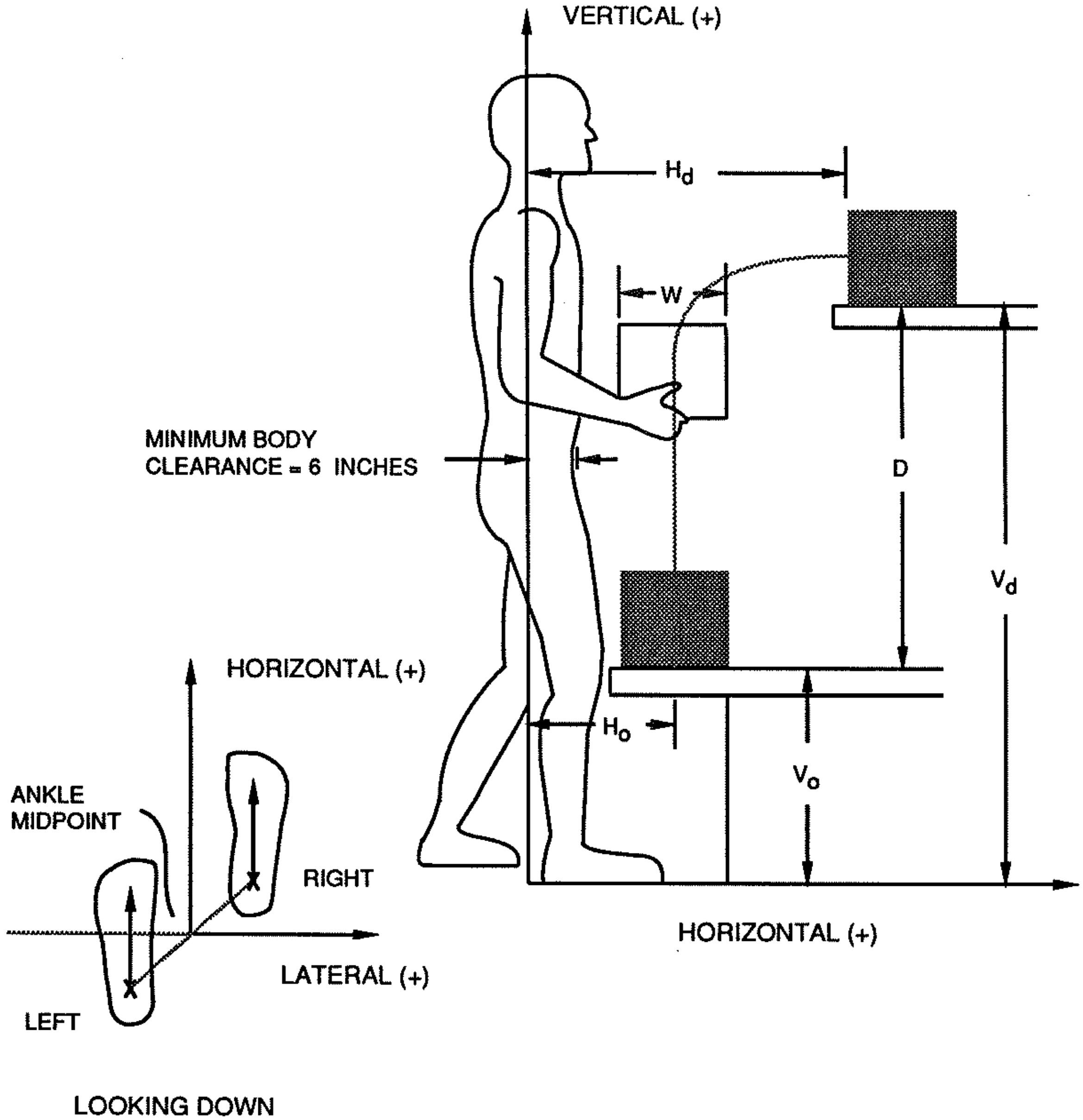



Figure B1
Illustration Of Important Lifting Task Variables.
("o" = Lift Origin, "d" = Lift Destination)
(Adapted From Keyserling And Chaffin, 1986)

HF = horizontal factor = $[6/H]$

VF = vertical factor = $[1 - .01|V - 30|]$

DF = distance factor = $[.7 + 3/D]$

FF = frequency factor = $[1 - F/F_{max}]$

H = the horizontal location of the hands at the origin of the lift. This value must be between 6 and 32 inches, measured from the ankles. Six inches is the minimum distance objects can be held from the body (body interference limit). And most individuals cannot reach beyond 32 inches (functional reach limit). A rule of thumb for H is $(W/2 + 6)$ where W equals the horizontal width of the object. $(W/2)$ implies that the hands grip the object at its center and 6 represents body interference limit.

V = the vertical location of the hands at the origin of the lift in inches. This value must be between 0 and 70 inches, the range of vertical reach for most people.

D = the distance from the origin to the destination of the lift in inches. This value must be between 10 inches and $(80 - V)$. For travel less than 10 inches, set $D = 10$ inches.

F = the frequency of lifting during the task in lifts per minute. (Set $F = 0$ if $F < .2$ lifts per minute)

Fmax = the maximum frequency that can be sustained in lifts per minute. This variable is selected from Table B1 below and depends upon the vertical location of the load (V) and the duration or period (P) of the lifting task.

Table B1
$F_{max}$ In Lifts Per Minute

| | Avg Vertical Location (in) | |
|---|---|---|
| Period (P) | $V > 30$ Standing | $V \le 30$ Stooped |
| $0 \le P \le 1$ Hour | 18 | 15 |
| $1 < P \le 8$ Hours | 15 | 12 |

P = the duration or period of the lifting task is assumed to be either occasional (less than one hour) or continuous (for eight hours).

A simple lifting task severity index (SI) can be used to rank tasks whose weight falls between the AL and MPL. The severity index is calculated as follows:

$$SI = (WT - AL) / (MPL - AL)$$

where:

WT = Weight of the object lifted. The weight must be between the Al and MPL.

The larger the severity index, the greater the risk of injury the task presents. A severity index close to 0.00 describes a task that slightly exceeds the Action Limit. While the severity index approaches 1.00 as the lifting task approaches the MPL.

### Recommended Lifting Limits

The NIOSH Action Limit (AL), as computed above, describes a lifting task that:

- would be within the strength capabilities of 75% of all women and 99% of all men.
- would produce about 770 pounds of compression on the low back (L5/S1 disc). This can be tolerated by most young, healthy workers, or
- would require an energy expenditure of about 3.5 kilocalories per minute for most individuals.

The NIOSH Maximum Permissible Limit (MPL), as computed above, describes a lifting task that:

- would be within the strength capabilities of less than 1% of women workers and 25% of all men,
- would produce about 1430 pounds of compression on the low back (L5/S1 disc). This **can not** be tolerated by most workers, or
- would require an energy expenditure of about 5.0 kilocalories per minute for most individuals.

These two limits form three zones for classifying lifting tasks. The three zones describe lifting tasks as:

(1) **Tasks That Are Above The MPL.**
These lifting tasks present an unacceptable risk to nearly all workers. Only engineering controls will reduce the risks of overexertion injuries. Engineering controls include workplace or tool redesign. For example, raising the height of the surface heavy items are stored on to minimize reach and bending of the back.

(2) **Tasks That Are Between The AL And MPL**
These lifting tasks present an unacceptable risk to some workers. Engineering and/or administrative controls can be used to reduce the risks of overexertion injuries. Administrative controls include worker selection and training. Worker selection would be based on the strength capabilities of the worker in relation to the strength requirements of the job. And worker training would focus on improving general fitness, increasing awareness of work hazards, and use of safer methods to perform tasks.

(3) **Tasks That Are Below The AL**
These lifting tasks present a nominal risk to most industrial workers. No action is required to control the risk of overexertion injuries.

**Benefits And Limitations Of The NIOSH Work Practices Guide For Manual Lifting**

Table B2 summarizes some of the benefits and limitations of the NIOSH Work Practices Guide for Manual Lifting.

Table B2
Benefits And Limitations Of NIOSH Work Practices Guide

| Benefits | Limitations |
|---|---|
| 1 It considers the epidemiology, psychophysics, biomechanics, and work physiology of lifting. | 1 It assumes lifting is smooth. Thus it cannot be used to evaluate tasks that are performed with jerking or tugging motions. |
| 2 It does not require hardware. | 2 It assumes that two-handed, symmetrical lifting in the sagittal plane is performed. It also assumes that twisting or sideways bending does not occur during the lift. |
| 3 It requires little expense. | 3 It is not appropriate for analysis of lifts involving objects wider than 30 inches. |
| 4 It is easy to use. | 4 It assumes that the worker's movements are unobstructed and that props or handling aids are not used. |
| | 5 It assumes that heat and cold stress are not present in the job. |
| | 6 It ignores the worker's grip strength and assumes he is at rest when not lifting. |

The Guide specifically ignores a number or important variables due to the limit of current information and understanding of overexertion injuries and illnesses. The guide's recommendations, thus, describe the level of risk for the best case scenario. For tasks that fail to meet the above criteria, the actual physical stress of a lifting task is probably more than that estimated by the Guide.

## Further Information

For further information, obtain a copy of the NIOSH Work Practices Guide from:

American Industrial Hygiene Association
475 Wolf Ledges Parkway
Akron, Ohio 44311-1087

Cost = $20.00.

Slide rule versions of the Guide that calculate the Action Limit and Maximum Permissible Limit can be obtained from:

The National Safety Council
444 North Michigan Ave.
Chicago, Illinois 60611

## References


Chaffin, D.B. & Andersson, G. (1984). Occupational biomechanics. New York: John Wiley & Sons.

Keyserling, W.M. & Chaffin D.B. (1986). Occupational ergonomics - methods to evaluate physical stress on the job. Annual Reviews in Public Health, 7, 77-104.

McMahan, P.B. (1984). Application of biomechanical principles and models to reduce railroad injuries from physical exertion (Report No. R-592). Washington, D.C.: Association of American Railroads, Research and Test Department.

National Institute for Occupational Safety and Health. (1981). Work practices guide for manual lifting (DHHS (NIOSH) Publication No. 81-122). Akron, Ohio: American Industrial Hygiene Association.

This page is intentionally blank

# Appendix C
# Further Details Regarding Switch Stand Design Investigation

This Appendix is divided into three parts:

- Part 1: Mechanical Advantage and the Crank/Connecting Rod Angle
- Part 2: Calculation of the Lever's Center of Gravity
- Part 3: Design Region Equations and Assumptions

## Part 1: Mechanical Advantage and the Crank/Connecting Rod Angle

The mechanical advantage of the switch stand varies as the lever angle varies. This is due to the changing angle between the crank and the connecting rod beneath the switch stand. As this angle deviates from 90°, as shown in Figure C1, the moment arm (d) of the crank falls. As this moment arm falls, the force transmitted through the connecting rod ($F_{rod}$) falls and thus the mechanical advantage of the stand falls accordingly.

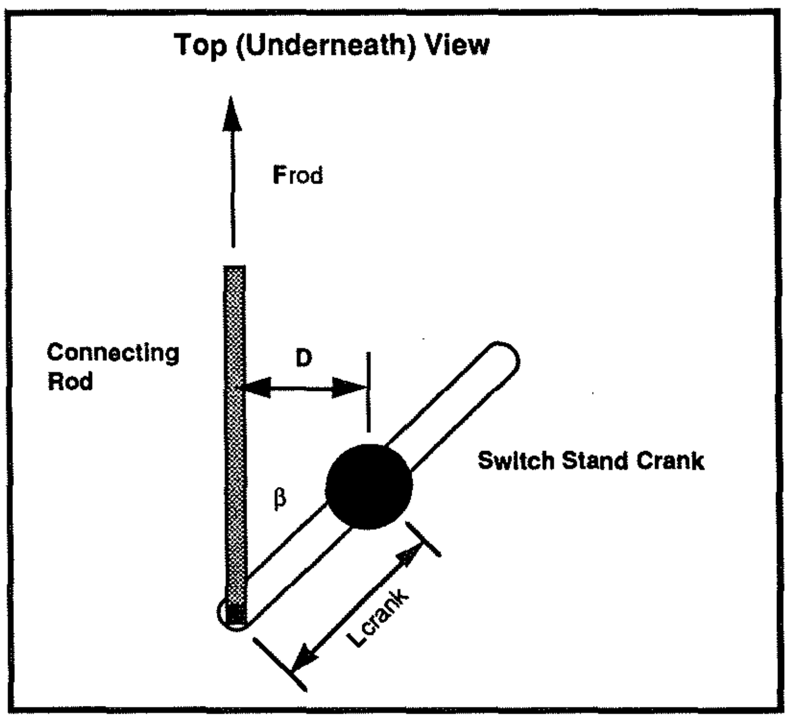



Figure C1
Stand Crank & Connecting Rod Angle

Some manufacturers' published mechanical advantages do not account for the orientation of the crank and connecting rod. Hence, these mechanical advantage specifications are "unadjusted." Equation (C2) shows the relationship between the actual mechanical advantage of the switch stand and the "unadjusted" mechanical advantage that is commonly referred to by manufacturers.

$$D = \mathrm{Sin}(\beta) \cdot L_{crank} \tag{C1}$$

thus,

$$MA = \mathrm{Sin}(\beta) \cdot MA_{unadjusted} \tag{C2}$$

where,

- $D$ = the crank's moment arm
- $L_{crank}$ = the length between the axis of the crank and the connection between the crank and connecting rod
- $\beta$ = the included angle between the crank and the connecting rod
- $MA_{unadjusted}$ = the mechanical advantage of the stand assuming the angle $\beta$ remains constant at 90°
- $MA$ = the actual mechanical advantage of the stand that accounts for the change in the angle $\beta$.

## Part 2: Calculation of the Lever's Center of Gravity

Before calculating connecting rod force requirements, the center of gravity of each switch stand lever type must be determined. Figure C2 illustrates.

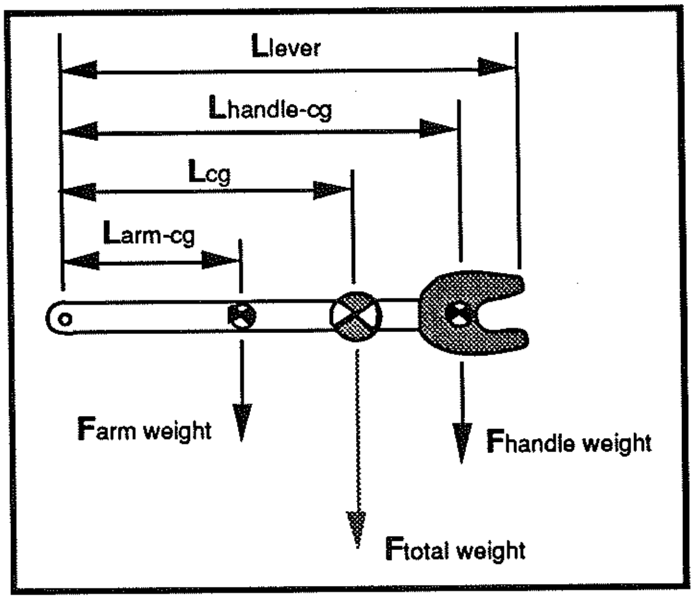



Figure C2
Free Body Diagram Used to Determine the Center of Gravity of the Entire Lever Given the Centers of Gravity and Weights of the Lever Components

To determine the location of the center of gravity of the lever arm, use the following equation:

$$L_{CG} = \frac{\left(L_{arm\text{-}cg} \cdot F_{arm\ weight}\right) + \left(L_{handle\text{-}cg} \cdot F_{handle\ weight}\right)}{\left(F_{arm\ weight} + F_{handle\ weight}\right)} \qquad \text{(C3)}$$

Where,

$L_{cg}$ = the distance from the lever axis to the center of gravity of the entire lever in inches (the lever arm and handle).

$L_{arm\text{-}cg}$ = the distance from the lever axis to the center of gravity of the lever arm in inches (not including the handle).

$L_{handle\text{-}cg}$ = the distance from the lever axis to the center of gravity of the handle in inches (not including the arm).

$F_{arm\ weight}$ = the weight of the lever arm in pounds (not including the handle).

$F_{handle\ weight}$ = the weight of the handle in pounds (not including the lever arm).

Table C1 details the weights and lengths of the lever components. It also provides the center of gravity locations for each switch stand using Equation (C3).

Table C1
Center of Gravity Locations for the New Century 50/51 and Racor 22P Levers
(in pounds and inches)

| | $L_{cg}$ | $L_{arm-cg}$ | $L_{handle-cg}$ | $F_{arm\ weight}$ | $F_{handle\ weight}$ |
|---|---|---|---|---|---|
| New Century Models 50/51 | 16.3<br>15.9 | 9.0 | 20.5 | 20 lbs. | 30 lbs.<br>35 lbs. |
| Racor Model 22 | 15.4<br>13.9 | 9.5 | 21.0 | 16 lbs.<br>16 lbs. | 17 lbs.<br>10 lbs. |

## Part 3: Design Region Equations and Assumptions

Equation (5) is used to determine the design region. The equation is an inequality when used to determine the design region, because the force produced by the hands (minus the effect of lever arm weight for the first 90° of operation and plus the effect of lever arm weight for the last 90° of operation) must equal or exceed the force required to move the switch rails ($F_{rod}$).

$$F_{rod} \le \left[ F_{hands} - F_{total\ weight} \cdot \cos(\theta) \cdot \frac{\left[ \left( L_{arm\text{-}cg} \cdot F_{arm\ weight} \right) + \left( L_{handle\text{-}cg} \cdot F_{handle\ weight} \right) \right]}{F_{total\ weight} \cdot L_{lever}} \right] \cdot X \cdot MA \qquad (5)$$

where,

X = a multiplier of the switch stand's current mechanical advantage. This is used because the current mechanical advantage of the switch stand is unknown or uncertain. If x=2, the mechanical advantage required to solve the equation is double the stand's current mechanical advantage.

solving for $F_{handle\ weight}$ (it's easier to solve for once substitutions are made),

$$F_{handle\ weight} \le \frac{\left( X \cdot MA \cdot F_{hands} \cdot L_{lever} \right) - \left( X \cdot MA \cdot \cos(\theta) \cdot L_{arm\text{-}cg} \cdot F_{arm\ weight} \right) - \left( L_{lever} \cdot F_{rod} \right)}{\left( X \cdot MA \cdot \cos(\theta) \cdot L_{handle\text{-}cg} \right)} \qquad (C4)$$

when 0° ≤ Theta ≤ 90°

$$F_{handle\ weight} \ge \frac{\left( X \cdot MA \cdot F_{hands} \cdot L_{lever} \right) - \left( X \cdot MA \cdot \cos(\theta) \cdot L_{arm\text{-}cg} \cdot F_{arm\ weight} \right) - \left( L_{lever} \cdot F_{rod} \right)}{\left( X \cdot MA \cdot \cos(\theta) \cdot L_{handle\text{-}cg} \right)} \qquad (C5)$$

when 90° < Theta ≤ 180°

where,

$L_{lever}$ = the effective length of the lever—the distance between the axis of the lever and the location where the hand applies force to the handle (usually the tip of the lever).

Table C2 lists the substitutions we make into Inequalities (C4) and (C5) so we can solve the inequalities for varying values of the 2 switch stand design parameters: X and $F_{handle\ weight}$. See Inequalities (C6) and (C7).

The substitutions listed in Table C2 require assumptions regarding the lever design: the handle remains 6 inches long for the New Century switch stand and 7 inches long for the Racor, the center of gravity of the handle does not change location relative to the end of the handle, and the weight of the lever arm per inch remains constant.

Table C2
Substitutions Made Into Inequalities (C4) and (C5) Producing Inequalities (C6) and (C7).

| For New Century 50 & 51 | For Racor 22 |
|---|---|
| $L_{lever} = 24 \cdot X$ | $L_{lever} = 26 \cdot X$ |
| $L_{arm\text{-}cg} = \frac{(24 \cdot X - 6)}{2}$ | $L_{arm\text{-}cg} = \frac{(26 \cdot X - 7)}{2}$ |
| $L_{handle\text{-}cg} = (24 \cdot X - 3.5)$ | $L_{handle\text{-}cg} = (26 \cdot X - 5)$ |
| $F_{arm\ weight} = 1.1(24 \cdot X - 6)$ | $F_{arm\ weight} = 0.84(26 \cdot X - 7)$ |

Note: all of the equations in the above table must be equal to or greater than 0. So, X must be greater than or equal to 0.27 or 0.3 in Inequalities (C6) and (C7).

for the New Century stand design, the following equation is used:

$$F_{handle\ weight} \begin{matrix} \le \\ \ge \end{matrix} \frac{[X \cdot MA \cdot F_{hands} \cdot (24X)] - [X \cdot MA \cdot \cos(\theta) \cdot (12X - 3) \cdot (26X - 7)] - [24X \cdot F_{rod}]}{[X \cdot MA \cdot \cos(\theta) \cdot (24X - 3.5)]} \quad \text{(C6)}$$

or

$$F_{handle\ weight} \begin{matrix} \le \\ \ge \end{matrix} \frac{\left[-312X^2 \cdot \cos(\theta) + 162X \cdot \cos(\theta) + 24X \cdot F_{hands} - 24\frac{F_{rod}}{MA} - 21 \cdot \cos(\theta)\right]}{\cos(\theta) \cdot (24X - 3.5)}$$

when 0° ≤ Theta ≤ 90° use (≤)
when 90° < Theta ≤ 180° use (≥)

for the Racor stand design, the following equation is used:

$$F_{handle\ weight} \begin{matrix} \le \\ \ge \end{matrix} \frac{[X \cdot MA \cdot F_{hands} \cdot (26X)] - [X \cdot MA \cdot \cos(\theta) \cdot (13X - 3.5) \cdot (22X - 6)] - [26X \cdot F_{rod}]}{[X \cdot MA \cdot \cos(\theta) \cdot (26X - 5)]} \quad \text{(C7)}$$

or

$$F_{handle\ weight} \begin{matrix} \le \\ \ge \end{matrix} \frac{\left[-286X^2 \cdot \cos(\theta) + 155X \cdot \cos(\theta) + 26X \cdot F_{hands} - 26\frac{F_{rod}}{MA} - 21 \cdot \cos(\theta)\right]}{\cos(\theta) \cdot (26X - 5)}$$

when 0° ≤ Theta ≤ 90° use (≤)
when 90° < Theta ≤ 180° use (≥)

## Inequalities That Define the Design Regions in Figures 11 and 12

The inequalities are listed by switch stand type, maintenance conditions, and lever sector (+90°-beginning of operation, -90°-end of operation).

### New Century Switch Stand (Models 50 and 51)

Switches after typical maintenance

Design Region 2

(+90°) $$F_{\text{handle weight}} \leq \frac{-312X^2 + 882X - 225}{24X - 3.5}$$

(-60°) $$F_{\text{handle weight}} \geq \frac{270X^2 + 1060X - 1892}{-20.8X + 3}$$

Design Region 1

(+60) $$F_{\text{handle weight}} \leq \frac{-270X^2 + 2660X - 280}{20.8X - 3}$$

(+30) $$F_{\text{handle weight}} \leq \frac{-156X^2 + 2001X - 452}{12.0X - 1.7}$$

(+0) $$X \geq 0.54$$

(-60) $$F_{\text{handle weight}} \geq \frac{270X^2 + 1900X - 1892}{-20.8X + 3.0}$$

Switches prior to typical maintenance

Design Region 2

(+90) $$F_{\text{handle weight}} \leq \frac{-312X^2 + 882X - 578}{24X - 3.5}$$

(-90) $$F_{\text{handle weight}} \geq \frac{312X^2 + 1878X - 5369}{-24X + 3.5}$$

Design Region 1

(+60) $$F_{\text{handle weight}} \leq \frac{-270X^2 + 2660X - 505}{20.8X - 3.0}$$

(+30) $$F_{\text{handle weight}} \leq \frac{-156X^2 + 2001X - 1083}{12.0X - 1.7}$$

(-90) $$F_{\text{handle weight}} \geq \frac{312X^2 + 2718X - 5369}{-24X + 3.5}$$

## Racor (Model 22)

Switches after typical maintenance

Design Region 2

(+90) $$F_{handle\ weight} \le \frac{-286X^2 + 935X - 1532}{26X - 5}$$

(-60) $$F_{handle\ weight} \ge \frac{248X^2 + 1166X - 2436}{-22.5X + 4.3}$$

(-90) $$F_{handle\ weight} \ge \frac{286X^2 + 2055X - 4316}{-26X + 5}$$

Design Region 1

(+90) $$F_{handle\ weight} \le \frac{-286X^2 + 3665X - 1532}{26X - 5}$$

(+60) $$F_{handle\ weight} \le \frac{-248X^2 + 2864X - 718}{22.5X - 4.3}$$

(-90) $$F_{handle\ weight} \ge \frac{286X^2 + 2965X - 4316}{-26X + 5.0}$$

Switches prior to typical maintenance

Design Region 2

(+90) $$F_{handle\ weight} \le \frac{-286X^2 + 935X - 1615}{26X - 5.0}$$

(-60) $$F_{handle\ weight} \ge \frac{248X^2 + 1166X - 4784}{-22.5X + 4.3}$$

Design Region 1

(+60) $$F_{handle\ weight} \le \frac{-248X^2 + 2864X - 1911}{22.5X - 4.3}$$

(+0) $X \ge 1.58$

(-60) $$F_{handle\ weight} \ge \frac{248X^2 + 2076X - 4784}{-22.5X + 4.3}$$