References
Dagan, R., E. Zaltzstein and R. Gorodischer. 1988. Methemoglobinemia in young infants with diarrhea. *Eur. J. Pediatr.* 147:87-89.
Kross, B. C., A. D. Ayebo and L. J. Fuortes. 1992. Methemoglobinemia: Nitrate toxicity in rural America. *Am. Fam. Physician* 46: 183-188.
Madison, R. J. and J. O Brunett. 1985. Overview of the occurrence of nitrate in groundwater of the United States, In *National Water Summary 1984*, Water Supply Paper 2275, 93-105. Reston, Va.: U.S. Geological Survey.
NRC (National Resource Council). 1995. *Nitrate and nitrite in drinking water*. Washington, D.C.: National Academy Press.
Simon, C., H. Manzke, H. Kay and G. Mrowetz. 1964. Uber vorkommen, pathogenese und Moglichkeiten zur prophylaxe der durch nitrit verursachten methmoglobinamie. *Zeitschrift fur Kinderheilkunde* 91:124-138.
Walton, G. 1951. Survey of literature relating to infant methemoglobinemia due to nitrate contaminated water. *Am. J. Publ. Health* 41:986-996.

Citrus Workers Resist Ergonomic Modifications to Picking Ladder

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J. A. Miles, W. E. Steinke

Abstract

Several ladder modifications were made to increase the safety and comfort of orchard workers. A sequence of these modifications were presented to crews picking citrus. Human factors related to worker objectives, motivation, and culture, as well as the existing piece rate compensation system, proved to be significant barriers to the acceptance of alternative ladders. An understanding of these issues is essential to engineers attempting to design alternative tools and systems to improve worker health and safety.

Keywords. Agricultural workers, Ladders, Citrus harvesting, Ergonomics, Safety.

Most citrus in California is picked by *pizcadores**. Because the picking season is very long (about nine months of the year in the California coastal region) compared to other crops, crews tend to specialize in citrus harvesting and do not migrate from crop to crop or area to area.

Citrus growers initially approached the Biological and Agricultural Engineering Department of the University of California, Davis, in 1987 to request assistance in reducing the number and severity of injuries suffered by citrus picking workers. Preliminary investigations were conducted by student design classes during 1988 and 1989 in which the students were able to identify a number of hazards related to the tools (ladders, bags, clippers, and gloves) the workers used. This data was used in formulating a research project to address these hazards.

The particular setting for this project may be as important to the conclusions as the design modifications which were made. The field study began about six months after a major freeze which destroyed most of the California citrus crop in December 1990. The industry was depressed, the quality of the fruit was low, and there was very high unemployment among the pizcadores.

Ladders were selected as the primary target for a design effort because many of the more serious injuries involved the use of ladders. Likewise, it was decided that the major constraint which needed to be addressed by the initial research effort was the acceptability of various ladder modifications to the labor force.

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* Mexican farm workers engaged in harvesting citrus fruits in the United States self-identify by using the term pizcadore (pronounced "pees-kah-dor"), a Spanish word used in Mexico to refer to a person who harvests corn.

Objectives

The primary objective of this research was to identify particular ladder characteristics which could be modified to improve the safety and comfort of citrus workers. A second objective was to determine the type of modifications which would be acceptable to the workers. In cooperation with representatives of the citrus industry, it was decided that alternative designs would not only have to reduce hazards, but would also have to:

- Maintain or improve harvest productivity.
- Maintain or improve fruit quality.
- Be compatible with existing systems for delivering the fruit to packing houses.
- Be economically viable.
- Be acceptable to the workers.

Background and Literature Review

A review of literature reveals four perspectives relevant to the acceptance of safety-related innovations: 1) the adoption perspective; 2) the market/infrastructure perspective; 3) the economic history perspective; and 4) the development perspective. The adoption perspective is the most pervasive approach, which proposes that individuals can be persuaded to adopt through communication efforts about the innovations. The market/infrastructure perspective states that the opportunity to adopt is often purposely unequal. Individuals do not execute decisions about innovations from free will as much as from a set of constraints that is provided to them from the outside. The economic history perspective states that the diffusion of innovations is a continual process through which the technological form and functions of an innovation is modified, along with the environment into which it may be adopted. The development perspective considers the impact of innovations on the welfare of individuals and groups. It attempts to predict the social and economic consequences of adopting an innovation (Brown, 1981).

This study considered the following seven basic characteristics of an innovation which determine the likelihood of its adoption:

1. *Relative advantage* is the degree to which the innovation is perceived as better than the ideas it supersedes. This may be measured in economic terms, social factors, prestige enhancement or debasement, convenience, or esthetic satisfaction (Rogers, 1983).
2. An innovation's *credibility* stems from the soundness of evidence for its value, or from its espousal by groups or individuals perceived to be highly respected by the potential adopter (Glaser, 1973).
3. *Compatibility* is the degree to which an innovation is perceived as being consistent with a potential adopter's existing values, past experiences, and needs (Rogers, 1983; Glaser and Ross, 1971).
4. *Complexity* refers to the degree which an innovation is perceived as difficult to use or understand (Rogers, 1983; Glaser, 1973). Generally, the more complex an innovation is perceived to be by potential adopters, the less rapid will be the rate of its adoption.
5. *Trialability* is the degree to which the innovation can be experimented with on a trial basis (Rogers, 1983; Glaser, 1973; Lin and Zaltman, 1973). It implies reversibility if the innovation has perceived negative outcomes.
6. *Observability* is the degree to which the results of the innovation are visible to others (Rogers, 1983; Glaser, 1973). *Visibility* stimulates communication of how a new idea is implemented, as well as the advantages resulting from its use among peers (Lin and Zaltman, 1973).
7. *Reinvention* refers to the degree to which an innovation is changed or modified in its process of adoption (Rogers, 1983; Lin and Zaltman, 1973). Innovations are not invariable over time; however, they are susceptible to refinement and elaboration by adopters. When modifications occur, acceptance of the original or essential idea is indicated, as well as the tendency of the adopter to take an active role in its implementation (Lin and Zaltman, 1973).

As identified by Rogers (1983), there are two roles which members hold within a social system that can affect the adoption of innovations—the opinion leader and the change agent. The opinion leader is found at the center of interpersonal communications networks and is highly conforming to the norms of the social system (Rogers, 1983). Change agents usually are not members of the same peer network as potential adopters (Glaser, 1981). They are usually individuals who influence the innovation decision of potential adopters in a direction deemed desirable by a change agency. They often use aides, or paraprofessional personnel, who can intensively contact clients to influence their decisions. Change agents are also feedback flow channels to bridge the chasm between the change agency and potential adopters. Change agents play an important role in selecting information which is relevant to potential adopters (Rogers, 1983; Glaser, 1981; Rothman et al., 1981).

Orchard Ladders

Ladders have been an important tool since early man. The basic attributes of this tool have changed very little, with most changes resulting from the availability of new materials or new fastening methods. In California, the current citrus picking ladders are fabricated from lightweight aluminum extrusions in which channel-shaped steps are riveted within channel side rails. The extruded steps fit between the side rails in such a way that the flat portion of the step is horizontal when the ladder is positioned at a lean angle of 76° above horizontal. Bipod ladders weigh approximately 3 kg/m (2 lb_m/ft) of length, while tripod ladders weigh approximately 4.5 kg/m (3.0 lb_m/ft) of length.

Past investigations (Fulton, 1982) and years of experience have shown that these ladders have a high degree of structural integrity. Structural failures are rare and when they do occur it is usually found that the ladder had initially been damaged in transport or storage. (The authors are aware of one failure which occurred after the ladder had been run over by a truck and was placed back into service without being repaired). Prior to 1970, the most common aluminum ladders where produced with side rails which were 6.4 cm (2.5 in.) deep. Since that time, most manufacturers have switched to 7.6 cm (3.0 in.) side rails to increase ladder stiffness and strength.

Approach

The authors approached a progressive citrus grower-packer in Ventura County, California, about becoming the major cooperator for this project, because this company showed a strong interest in developing improved systems for its citrus harvesting crews. The company employed three separate crews of pizcadores. All of the workers had several years of experience picking citrus and had worked for this grower for a minimum of five years.

The selected approach was to place a Spanish speaking graduate student with the crews to monitor existing practices and to spend enough time with each crew so that the pizcadores did not feel threatened by his presence. This student spent part of his time learning to pick fruit. He collected numerical data relative to the use of ladders and took many hours of video tape to record the style and technique of individual workers. At night, he offered English instruction for those workers who had a desire to improve their English language skills. In short, the student had one role as an observer/recorder and another as an agent of change. As the graduate student began to integrate into the pizcadores environment, he began to formally, and informally, interview workers about their goals and motivations and, in the process, attempted to determine what type of changes in work environment would be attractive to them. While the responses did not lend themselves to statistical analysis, the authors believe the responses are very important to any designer attempting to modify this type of work environment.

Worker Attitudes and Beliefs

1. During the interviews it was found that the pizcadores are extremely skeptical about anyone who professes to help them in any way. They believed that any change made to the system would be for the benefit of management and, generally, to their detriment.
2. Their primary objective is to earn as much money as possible. This includes both maximizing their daily wage and obtaining as much job security as possible.
3. They profess that health and safety are important, but also that they are unwilling to participate in any practice which they believe may reduce their earnings or earning potential.
4. Objectives related to having enough energy at the end of the day for recreational or family activities rated very low compared to salary issues.
5. Almost all of the pizcadores stated that the low-cost housing provided by the company was an important benefit, and about half of the workers also mentioned that company-provided health insurance was a factor in their continuing to work for this company.

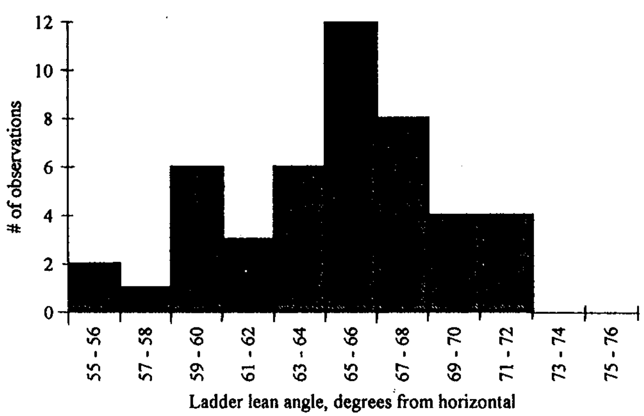

Figure 1–Observed ladder lean angle.

6. The workers are concerned, perhaps even threatened, by potential engineering innovations. They are very aware of the large labor surplus. They believed that the primary reason they are currently employed is because they are working in a difficult and strenuous environment. They express the belief that if the engineers make the job easier to do, management is likely to reduce their pay, or hire less costly workers.

While the above observations were made prior to introducing any ladder modifications, the significance of these perceptions and motivations was reinforced many times during the field season.

Another characteristic which was underestimated by the authors at the beginning of the study was the tremendous peer pressure exerted by the crew. Out of more than 70 pizcadores, no individual would either identify himself or any other member of the crew as an unofficial leader or spokesman for the group. Peer pressure was so great that only on two occasions during the study did a pizcadore volunteer to use a modified ladder, and in each case this was only for one day. Pizcadores gladly used modified designs if they were asked to do so, but did not feel free to do so on their own initiative. Thus while the graduate student attempted to be a change agent, no opinion leader was ever identified. Pressure to maintain the current system tended to remove the option of any individual to exercise free decision.

Introduction of Modified Ladders

Given these circumstances, it might seem ridiculous to attempt to introduce alternative designs into this environment. It was recognized from the beginning that the pizcadores were not empowered to make the final adoption decisions, but that their comments and criticisms could be very useful in refining designs which could be effective and which would meet minimum resistance if an implementation decision was made. Early involvement also had the potential of transferring some of the ownership of an alternative design to the group as a whole, since their inputs would be used to modify and shape the final design.

Field Observations

Observations by the graduate student combined with previous observations and video tape reviews by the authors and their students resulted in the identification of several hazard reduction opportunities. These are discussed in the following paragraphs.

The standard ladder lean angle is 76° above the horizontal plane. This angle has been selected because it provides a 4:1 ratio of rise to run which has been found to be a comfortable and safe geometry. It allows a person to climb the ladder while placing both hands on the ladder. Figure 1 shows a distribution of lean angles for citrus ladders and indicates the actual lean angle is approximately 65°. This distribution did not appear to be affected by ladder size or type or by tree size.

Citrus workers do not use both hands while climbing the ladder. They walk up the ladder, occasionally stabilizing themselves with one hand. The additional space between the ladder and their body is needed to accommodate the picking bag which holds up to 35 kg (77 lb) of fruit.

Close observation shows that the workers seldom stand squarely on the ladder. Their feet are usually more nearly parallel to the steps than perpendicular to them. They reach out in front of their bodies to pick fruit, which is most often in a lateral direction with respect to the ladder. One soon observes that the pizcadores seem to be balancing on the edge of the steps, rather than using the whole step to support their weight. Further observation shows that the steps are not level, but are inclined forward as a result of the ladder being positioned at near 65° instead of 76° angle of lean. The older ladders provide additional verification in that the rear edge of the steps are much more worn than any other part of the step. This very narrow foot support places a stress concentration along the bottom of the foot. It also reduces the natural stability one gets by moving his foot slightly to redistribute the balance of forces.

Hazard Reduction

Targets for hazard reduction became: 1) redesign ladder steps to be more nearly level under actual working conditions; 2) increase the area of the step to allow the worker to support the entire foot and provide increased stability and reduced fatigue; 3) increase lateral step friction to prevent slippage when the worker leans from the side of the ladder; and 4) address problems related to mud which may cling to the workers' boots.

A second type of hazard was identified by observing the process the pizcadores use to lift a long ladder from the ground (horizontal) to a near vertical position. A short ladder can be pivoted about the center of gravity and thus is easily set. The center of gravity of a 5.5-m (18-ft) picking ladder is 2.6 m (8.5 ft) above the base of the ladder. The pizcadore must apply a substantial torque to the base of the ladder to accelerate it to the vertical position and then stop it once it gets there. The action also places high stress on the worker's lower back, particularly if the ground happens to be wet and slippery.

Workers complain about this stress and frequently propose cutting the top steps out of the ladder in order to make it "lighter". The authors were able to lower the center of gravity of 5.5-m (18-ft) ladders from 2.6 to 2.3 m (8.5 to 7.5 ft) above the ground by adding 2 kg (4.4 lb.) to the base of the ladder side rails. When this was tested with the lemon picking crew, typical comments were:

> "It is a little bit heavier, but not in excess, because it is easier to manipulate as I move around the tree."
>
> "I don't feel like the ladder is going to flip forward on me when I am standing on the top half of the ladder."
>
> "I can reach out further to get the fruit because the ladder holds its balance better."
>
> "I can pull this ladder out of the tree easier because the feet stay on the ground better."
>
> "It is okay to use, but since it is heavier, I think it might slow me down."

While individual comments were complimentary, the workers would not select these ladders unless they were asked to do so. The foreman explained, "The guys don't want to have anything to do with something that adds weight to a piece of equipment, except for the bag. In fact, they want larger bags. If you add any weight to the ladder, they don't want to use it. They say it will slow them down. But they don't think a heavier bag will slow them down".

The second modified ladder to be introduced to the crew (fig. 2) was a 2.4-m (8-ft) tripod ladder in which the steps had been replaced with aluminum diamond plate providing level treads, with a width of 16 cm (6.3 in.), when the ladder lean angle was 65°. Worker response was immediate. While they liked the "platform-type" steps and reported significantly improved balance and an increased sense of security, they completely rejected the ladder because it weighed 9.5 kg (21 lb) compared to the standard ladder which weighed about 6.7 kg (14.7 lb).

At this point, it was learned that the pizcadores had a strong preference for the old ladders, the one manufactured in the 1960s with the 6.4-cm (2.5-in.) side rails

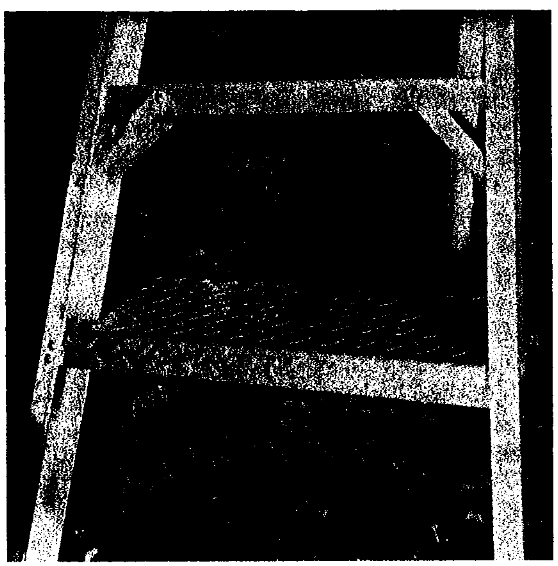

Figure 2–Aluminum diamond plate used to enlarge the ladder steps and change the step angle to near horizontal when the ladder lean angle is 65°.

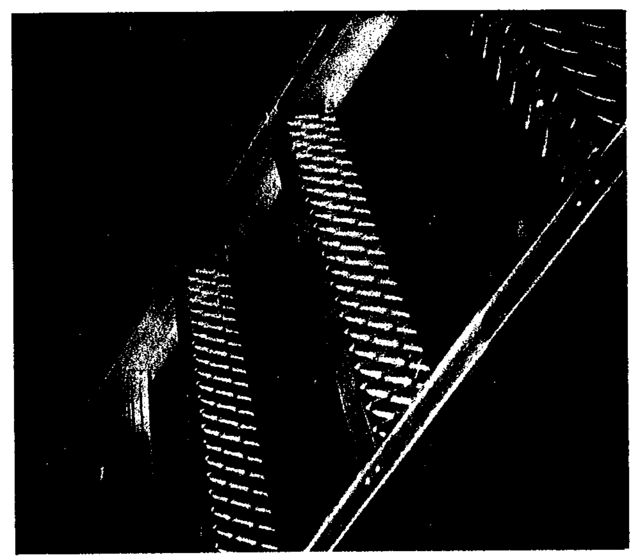

Figure 3–Picking ladder which used expanded aluminum on the lower steps to increase friction, remove mud, change the step angle to near horizontal with a 65° ladder lean angle, and retain a "light feel".

because these were about 0.7 kg (1.5 lb.) lighter than the newer ladders constructed using 7.6-cm (3-in.) side rails.

Several attempts at designing large, lightweight steps resulted in a ladder in which the steps were fabricated from expanded aluminum with 15 cm (5.9 in.) wide steps. As a response to earlier crew comments which argued that the third leg was not beneficial to the workers, no third leg was placed on this ladder. Again, response was immediate. The workers wanted a third leg, so one was fabricated for the ladder. The workers then expressed an objection to placing their hands on the rough surface provided by the expanded aluminum and also expressed concern that standing on the expanded aluminum would cause their boots to wear out too quickly.

The final (and current) effort in this area modified only the lowest four steps, since these usually do not come into contact with the workers' hands. A series of 5.7-cm (2.25-in.) diameter holes were drilled in the original step channel and it was mounted upside down in the ladder rails (fig. 3). Expanded aluminum was formed to fit inside the steps to provide a high friction surface which was nearly horizontal at a 65° lean angle. This design is particularly effective at removing mud from boots and providing high friction as the worker ascends and descends the ladder.

Changing the angles of conventional steps to make them horizontal at 65° lean angles met with mixed results. The workers like the steps to lean slightly forward, so perhaps a horizontal step at 70° lean angle would meet more acceptance.

Conclusions

Current workers clearly feel threatened by ladders which may be easier to use. Each of the ladder modifications removed some of the significance of worker strength, endurance, and special skills to which they credit their current employment. If the designer expects an endorsement from the pizcadores, the design will need to build upon current skill levels, and somehow allow the worker to increase his earnings potential.

Redesign of tools to enhance worker safety must address the productivity, quality, and cost issues imposed by management, but must also address a wide range of human factors in order to gain worker acceptance. Most of the ladder modifications introduced to the field were recognized as having relative advantage and credibility with respect to safety, but not with respect to worker income. Compatibility was high in that none of the proposed changes required altering other parts of the picking system. There was no change in job complexity and because of the high degree of compatibility, trialability was also easy to accomplish.

Observability presented a significant problem. Even the current high rates of injury do not occur so frequently that one can personally observe the lack of such injuries. Also, the type of modifications which were proposed were the type which would tend to prevent an injury from happening, not the type which would save one's life when an accident occurs. The workers believed that any additional ladder weight would eventually cause fatigue and thus reduce their productivity (earnings).

Because new tool adoption will be much easier if the workers feel some ownership in the project, the authors believe efforts toward fostering reinvention are valuable to the implementation of safer systems for farm workers. Workers were very willing to critique design alternatives. Incorporating that information in a way which ties the worker to the improved concept remains a challenge.

References

Brown, L. A. 1981. *Innovation Diffusion: A New Perspective.* London, U.K.: Methuen and Co., Ltd.

Fulton, F. M. 1982. Safety factors analysis for lemon picking with a tri-leg aluminum ladder. Consulting Report for Limoneira Co. Santa Paula, Calif.: FM Fulton Consulting.

Glaser, E. M. 1973. Knowledge transfer and institutional change. *Professional Psychol.* 4:334-344.

———. 1981. Durability of innovations in human science organizations. *Knowledge* 3(2):167-185.

Glaser, E. M. and H. L. Ross. 1971. Increasing the utilization of applied research results. Final Report to Nat. Inst. of Mental Health, Grant No. 5R12 MH 09250-02. Los Angeles, Calif.: Human Interaction Research Inst.

Lin, N. and G. Zaltman. 1973. *Dimensions of Innovations. Processes and Phenomena of Social Change*, ed. Gerald Zaltman. New York: John Wiley & Sons.

Rogers, E. M. 1983. *Diffusion of Innovations*, 3rd Ed. New York.: MacMillan Publishing Co., Inc.

Rothman, J., J. L. Erlich and J. G. Teresa. 1981. *Changing Organizations and Community Programs.* Beverly Hills, Calif.: Sage Publications.