Case study

Cost effectiveness of ergonomics and quality improvements in electronics manufacturing

Martin G. Helander a, George J. Burri b

a Department of Industrial Engineering, SUNY at Buffalo, Buffalo, NY 14260, USA
b Ergonomics Coordinator, IBM Corporation, P.O. Box 1328, Boca Raton, FL 33429, USA

Received January 12, 1993; accepted in revised form March 7, 1994

Abstract

This paper describes the increasing emphasis on ergonomics in the manufacturing plants of IBM. Since 1978, 250,000 engineering hours have been devoted to ergonomics training. As a result a systematic approach to ergonomics improvement of manufacturing facilities has been implemented. This involves an analysis of the production environment including equipment, processes, ambient factors and job procedures. Information is collected through interviews of management, operators, and first-line supervisions, and complemented thorough field measurements of ergonomic parameters. Individual workstations as well as processes are analyzed with the purpose of modifying processes, reallocating tasks between automated devices and human operators and optimizing workstation design. Four case studies of industrial improvements are presented and analyzed in terms of improved productivity, quality, and reduction of injuries. All four studies proved to be good investments. Since its implementation around 1978, it is estimated that ergonomics improvements have resulted in cost savings of approximately $130 million.

Relevance to industry

Ergonomics improvements of four industrial processes are described. The main emphasis was to improve production, and manufacturing yield. The primary economic benefits were derived from improvements in productivity and quality. There were also improvements in injury rates and operator satisfaction.

Keywords: Ergonomics; Manufacturing; Productivity; Quality control; Training

1. Development of ergonomics in IBM

IBM has a long-standing tradition in human factors and ergonomics. In the late 1950's laboratories were established for design of hardware, such as keyboards. Presently much of human factors design is concerned with usability of software, and this preoccupies about 80% of human factors specialists in IBM. The efforts in manufacturing ergonomics are recent and comparatively modest, but as we will present our case, important to enhance worker comfort and productivity. During the last few years ergonomics has become an integrated part of the business. It consists of results-oriented training programs, communication tools, policy statements, measure-
ments systems, guidelines for implementation and self-assessment, periodic audits, and employee involvement. Several functional areas have been involved including: Manufacturing, Human Factors, Health and Safety, Medical, Personnel, Government Programs, the VDT Project Office, Advanced Engineering for Manufacturing and Technical Education.

Training in ergonomics started in the late 1970's and for the first few years it was directed primarily at engineers and managers. Since 1985 the audience has been broadened to include operators, who participate in design of manufacturing processes and workstations. During the time period to 1992 about 250,000 person hours were devoted to training. Centers for ergonomic coo-

Fig. 1. A systems approach to assessment of ergonomics and productivity in manufacturing.
dination were established world-wide at 45 locations and a communications network was established for distribution of process standards and guidelines and programs for injury reduction and productivity/quality improvements. Promotional materials were developed including videotapes, brochures, short texts, and a newsletter “Human Connection”, which was distributed internally as well as externally. A travelling exhibition was developed and displayed at IBM plants in Europe, Canada, and the United States. This exhibition allowed visitors to obtain hands-on experience by evaluating workstations and handtools. This networking of ergonomics information was important since several plants could compare their situation and implement changes.

2. A systems approach to ergonomics

There is an increasing realization in industry that ergonomics is important, not only for worker comfort, safety and health but to improve productivity and quality in manufacturing. Because of increased technological complexity in manufacturing environments, the need for ergonomic design has actually increased. Although many manufacturing tasks can be handled by computerized automated systems, the very existence of these systems makes the performance of the human operator even more critical than previously. An operator must be able to monitor the process using parameters for quality control and quickly intervene when process parameters are out of bounds. In case of equipment failure the operator must also be able to “take over the work” and temporarily act as a back-up for the automated processes.

Ergonomic improvements hence have a dual purpose: worker comfort and plant productivity. Whatever the emphasis, the methodology for solving problems has become fairly standardized in industrial settings. Fig. 1 illustrates a systems approach for analyzing ergonomics problems, and the types of variables that are used to assess problems. The production process is conceptualized using an environment-operator system. The environment is composed of four subsystems: equipment, process, ambient factors, and job procedures. The operator part is composed of three subsystems: manufacturing/assembly, quality control and process monitoring, which constitute the three major operator activities in modern manufacturing, and most jobs involve a mix of these three activities.

The boxes at the bottom of the figure illustrate the types of data that may be collected. The left side, “Production Environment”, illustrates what information is collected to document the manufacturing system. The right side, “Operator”, emphasizes the information obtained from employees with respect to ergonomics and quality. The feedback loop to “Production Environment” indicates that in a third step alternatives for workstation design, job design, production methods and machinery are considered, and there may be design changes in the production system. At first an ergonomic checklist may be used during inspection of an operation to identify possible deficiencies in workstation design and the production process. Ergonomic variables are then quantified, for example by obtaining measures of the ambient environment biomechanics and anthropometric fit of workstations.

Elements which impede human information processing (cognitive) activities of the operator may be identified. This could involve an analysis of the usability of displayed information, such as the arrangement of process control parameters on a VDT screen. It may also involve an analysis of work procedures, as they are imposed by the design of the manufacturing process.

On the operator side of the system, most of the information is collected through interaction with operators. This includes evaluation and operator opinions on alternatives for improvements of processes and workstations. Other ancillary information may be collected including measures of job satisfaction, injuries, and absenteeism. At this stage we are also concerned about cognitive and perceptual requirements. Several of the case studies presented below give examples of such problems.

An analysis is then undertaken with the purpose of simplifying and redesigning work procedures, to enhance productivity as well as operator
comfort and convenience. The analysis must consider alternative processes and technologies for manufacturing, and is therefore best performed by an engineer with knowledge in ergonomics.

2.1. Procedure for ergonomics and productivity assessments

Table 1 documents the type of data that is collected, and the source of information. There are five consecutive steps.

The analyst must first become familiar with the operation. Much information may be obtained through conversations (unstructured interviews) with management. The main purpose is to assess problems in the current production process, and several types of statistics may be collected including: measures of yield, throughput, types of defects, job descriptions, rate of absenteeism and injury rates. This information is used as a base-line to assess any effects of future improvements. It is also used to establish a viable goal for the study.

The second step is a walk-through inspection in the plant. An ergonomics checklist is used as a frame of reference to collect systematic data at different workstations. Notes are taken, and this information is later used as a background when interviewing operators.

The third step is to interview operators. This gives an opportunity to address a variety of ergonomic factors, including: workstation design features, handtools, fixtures, work heights, shift work, job rotation, training, lighting, noise, temperature, problems with house keeping, operator job satisfaction, aches and pains, injuries, and accidents (see Grandjean, 1985; Helander, 1991). Photographs and videos can be taken to document workstations and potential ergonomic problems. Video recordings are particularly useful in evaluating biomechanical aspects of operator movements and workposture to assess any potential risk for injuries due to cumulative trauma disorder, and over-exertion due to manual handling. Questionnaires can be distributed and used to collect standardized data for many operators. It may also be necessary to perform a more detailed task-analysis of the work of various workstations. A procedure for this has been documented by Burri and Helander (1991a). This information is then combined and validated against the previous assessment in step 2.

The purpose of step 4 is to understand the present manufacturing process and possibilities for future modifications of the process. The best source of information may be first-line supervisors who are concerned with the day-to-day operation. The focus is on the documentation of prob-

<table>
<thead>
<tr>
<th>Source of information</th>
<th>Method</th>
<th>Data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Plant walk through</td>
<td>Ergonomics checklist</td>
<td>Investigator observations on ergonomics and productivity. To be verified by operators.</td>
</tr>
<tr>
<td>5. Field measurements</td>
<td>Photometer, Sound level meter, Workstations design measures</td>
<td>Measures of ambient environment. Size of workstations.</td>
</tr>
</tbody>
</table>
lems that cause disturbances and identification of alternative processes that may improve productivity, quality and yield. First-line supervisors can also validate some of the information provided by operators and management.

In the final step ergonomic variables are measured, including information on ambient environmental factors, size and height of worksurfaces, arrangement of workstations, and so forth. These measures can be compared to ergonomic requirements (e.g., Eastman Kodak Co., 1983).

This procedure has developed over several
years. In the beginning of the 1980's there was no clear procedure, rather the information in Table 1 was collected in a less structured fashion. During the last couple of years we have found the procedure beneficial, since it establishes a logical format.

Below we describe four case studies where this methodology was used, and the effects on productivity were measured. Much of the data in Table 1 remains company confidential and cannot be reported in this paper.

3. Case studies of ergonomics improvement in manufacturing

3.1. Design of assembly workstations at IBM in Boulder

The first case study illustrates an early example at IBM in Boulder that involved manufacturing of subassemblies for copier machines (Short, 1981; Hasselquist, 1981). Fig. 2 illustrates a workstation before the redesign. There were several problems of ergonomics nature. The workstation was disorganized. The task arrangements did not allow the operator to sit, and there were awkward hand postures for both the right and left hands. The illumination level was below the requirements for inspection tasks, and the task was obscured by the work arrangements.

The workstation was redesigned to solve these problems, see Fig. 3. In addition, pneumatic screwdrivers were brought in, and the work area was rearranged. Before the redesign 4.2 operators were required to produce this subassembly according to the production schedule. After redesign the same job was performed with 3.0 operators, corresponding to a saving of 29%. Predetermined time standards were calculated for both cases and showed a reduction from 0.70 hours per unit to 0.55 hours per unit, corresponding to 23% improvement. This indicates that predetermined time and motion studies (PTMS) can be used to predict gains in productivity and evaluate the impact of alternative solutions for redesign.

The quality of production improved, the comfort of the operator increased significantly and several potential causes of cumulative trauma injuries were removed. The savings of these latter benefits are more difficult to assess, and were therefore left out.

The cost for the engineering analysis and design was one man-month at $6,000. The installation of the new workstations was $3,200 for the labor and $2,400 for the hardware for a total cost of $11,600.

Based on the PTMS calculations and improved quality the savings were $60,000 the first year (Short, 1981). The benefit–cost ratio of this productivity improvement was hence substantial.

3.2. Redesign of manufacturing facility in IBM Boulder

In 1983 the manufacturing of an automatic finishing facility for diskettes was moved from the plant in Boca Raton to Boulder. This was a 50,000 square foot facility. This move was undertaken to balance the workload between the two locations, and the decision was not cost-justified. In fact the diskette manufacturing facility had been in existence for many years in Boca Raton. Production had been optimized, there were skilled operators and the equipment was fully depreciated. The cost for moving was projected to over $300,000, out of which the cost for engineering design was $100,000 and for technicians to take out equipment and reinstall about $120,000. The remaining $80,000 was for equipment and materials. Management in Boulder had previously witnessed the success of several ergonomic interventions, including the one mentioned above, and requested an ergonomic review of the installation in Boca Raton before it was relocated.

In Boca Raton the noise level was high with 80–85 dB(A). There was reflected glare from painted surfaces and the polished concrete floor. Carts for handling were difficult to push. Cartridges for storing diskettes varied in weight from 20 pounds to 5 pounds. The 5-pound cartridge was a new design that simplified handling. The illumination level varied throughout the facility between 300 and 1000 lux, the latter being more appropriate for this type of work. Finally there
were several aesthetic aspects including a cluttered appearance of overhead ducts.

These findings were discussed in detail with engineers responsible for the transfer. The new facility solved the problems discovered by the ergonomics review. This involved a dropped acoustic ceiling which lowered the noise to 75 dB(A), use of 5-pound cartridges, an illumination level of 1000 lux, and an aesthetic work environment. The modifications were accomplished within budget constraints. This resulted in a much more pleasing environment.

Given that the production facility had been running very efficiently in Boca Raton, few improvements, if any, were expected in productivity. At the most 5 to 10 percent could be expected due to minor improvements in efficiency which are typical of relocations. The first year business results were significant. Although the manufacturing process remained identical, the overall production costs were reduced by 20 percent. Management attributed half this reduction to improved quality and employee satisfaction which was brought about through attention to ergonomics. This translated into annual cost savings of approximately $500,000 (Long, 1984).

This case study illustrates the importance of design review and that changes made implemented early during design seldom increase costs.

3.3. Redesign of microscope workstation in IBM San Jose

Work with microscopes is common in IBM. At the plant in San Jose there were approximately 1200 microscope operators performing micro-assembly and visual inspection. Due to the static workposture and visual requirements, microscope work can be very taxing. Many operators have difficulties to adjust the focusing of the eyes to fit the requirements of the microscope and complaints of visual fatigue are common (Helander et al., 1990). To alleviate the problems with static work posture it is important to support the body and the arms. At this operation in San Jose, operators used a fixed height workstation, which resulted in an uncomfortable workposture with raised arms, see Fig. 4. This job required the use of a miniature screwdriver and operators were concerned about possible cumulative trauma injuries due to the pinch grip and awkward hand posture.

Fig. 4. Workstation with microscope for assembly of parts at IBM, San Jose. Note the poor posture of the right hand holding screwdriver, and elevated arms.
The workstation was redesigned. An experimental miniature power screwdriver was found in Germany, and modified to meet U.S. electrical requirements and safety standards. An electrical height-adjustable work table was obtained, see Fig. 5. The range for adjustability was chosen, so that it could accommodate multiple shift work with operators of different size. A split level adjustability of the table was used to lower the surfaces for storage of parts and reduce reaching distances. In addition to these engineering solutions job rotation was implemented, thereby reducing possible strain due to static workposture.

The problems created by micro-miniaturiza-
tion were solved, miniature power tools and adjustable benches were provided, costs and injuries were reduced. The savings for this and similar workstations amounted to $1.1 million during the first year (Grossmith, 1990).

3.4. Improvements in the manufacturing of circuit boards at IBM Austin

In 1988, several ergonomic improvements were undertaken at this location. We describe three of them here: Enhanced illumination for visual inspection, Facilitation of manual materials handling, and Improvement of machine tools.

3.4.1. Enhanced illumination for visual inspection

At this location automatic machines were used for insertion of components into circuit boards. In addition to process monitoring, machine operators also performed visual inspection and quality control of the inserted components. During interviews of operators it became obvious that the illumination level was inadequate for visual inspection, see Fig. 6. Although some areas had an appropriate illumination level of 1000 lux, several work areas were as low as 120 lux. It was decided to increase the illumination level to 1000 lux throughout. This is generally considered a minimal requirement for visual inspection of small parts (Eastman Kodak Co., 1983). It is worth mentioning that management were not aware of this problem. They thought that the operators' task was primarily to monitor the process, and they were not aware of the extent of quality control that actually took place, see Fig. 6.

The increased illumination was achieved by installation of fluorescent tubes, switching on lights which had been turned off to conserve energy, lowering light fixtures from the ceiling and installing windows in walls for outside light, see Fig. 7.

With the increased illumination the detection rate of faulty items improved, even in areas for routine handling of products and supplies. The yield of the process improved dramatically. Operators confirmed the beneficial effects of the improved illumination. Table 2 summarizes the improvements in yield and productivity for this and the other improvements described below.

The outside windows were beneficial for several reasons. In the first place they improve the illumination level, but even more important is that they created an aesthetic and friendly environment. They are also helpful as landmarks for

Fig. 7. Visual inspection of IBM, Austin after the redesign. The ambient illumination level was increased, and windows were installed at the far end of the room.
operators to orient themselves in the plant, and they create better awareness to the time of day, which is particularly important for shift work. These types of arguments are often brought forth in European locations of IBM, where in several countries outside windows are mandated by law.

3.4.2. Facilitation of manual materials handling

After the components had been inserted and inspected they were soldered automatically in a wave solder operation stored in tote pans, placed on a conveyor and moved to a location where remaining components were installed manually, see Fig. 8.

There were obvious problems with workposture due to the task itself and due to manual handling. The tote pans were designed to hold 25 boards, and several operators complained about back pain caused by the heavy weight. The lifting requirements were analyzed using NIOSH lifting guidelines and a computer program by Liberty Mutual called “Materials Handling Evaluator”. It turned out that the tote pan with 25 boards did not violate these guidelines. Nonetheless the tote pan was redesigned to hold only 12 boards, and as a result operators were satisfied and there were no further complaints.

Armed with the necessary background information (see stages 1, 2, and 3 in Table 1) a task analysis was performed. (These results have been reported previously, see Burri and Helander 1991a). The most significant result from the task analysis was that the 12-board tote pan was eventually eliminated and replaced by a pass-through cart system for individual handling of the boards. This reduced the postural strain considerably.

Task illumination with magnification was also installed and used by operators. In this case, the non-adjustable workbenches were not changed. Rather operators were trained to use the height-adjustable chair and foot rest to accommodate variability in body size. In addition, operators and supervisors were trained in ergonomic principles, such as appropriate illumination, and how to assume a good workposture.

This case study illustrates the importance of operator involvement in redesign and operator training in ergonomics. Training has a beneficial effect since operators can “look out for themselves”, identify ergonomic problems, and be-

Fig. 8. Manual insertion of components at IBM, Austin before redesign of workstations. Tote-pans and conveyors are used for material handling.
come qualified to participate in the redesign of processes and workstations.

3.4.3. Improvement of machine tools

A different posture problem was noted at an operation where thousands of holes are drilled automatically into electronic circuit boards. Drill bits of different types were stored at the front of the machine. From this location the machine would change bits automatically during the process. This design required a long reach for machine operators to set up and remove the product.
from the machine. This caused an awkward body posture, because the operator had to stay clear of the sharp drills bits, see Fig. 9. An ergonomics awareness workshop was given to engineers supporting the drill operation. Simultaneously older drill machines were being replaced and new machines with more drill bits and greater capacity were installed. The new machines actually exacerbated the posture problem and additional deliveries were suspended.

A few weeks later the engineers located a drill machine where the drill bits are positioned next to the drill chuck. This allowed for a more reasonable workposture, see Fig. 10. These machines significantly reduced the operators' reaching distance, which improved work posture. Calculations using PTMS for 20 machines in operation 24 hours a day revealed time savings corresponding to $270,000 per year (Cadigan, 1988).

This case study illustrates the importance of ergonomics specifications for machine tools and automation. Engineers who design processes and order machines must learn to assume a responsibility to analyze the ergonomic implications of different design alternatives. Training of engineers is therefore necessary.

3.5. Cost reduction at IBM Austin

Table 2 summarizes the projected and actual reduction of costs for the three case studies and other improvements at IBM Austin.

Based on our experience from previous studies we projected improvements in yield of 20%, operator productivity of 25%, and a reduction of injuries of 20%. Actual improvements were close to our predictions, and resulted in a cost reduction of $7,375,000 (Lakoski, 1988). The cost of materials for ergonomic improvements (such as improved illumination) was $66,400, and for engineering time about $120,000. The benefit–cost ratio for these improvements was approximately 40 for the first year, or phrased differently the payback time was about one week.

The reduction of injuries was fairly minor compared to the improvements in productivity and yield. However, there were additional intangible improvements of operator comfort, convenience and job satisfaction. As with the other case studies these are difficult to quantify in terms of cost savings, but nonetheless are of great importance to IBM. Management was impressed by the results and hired two ergonomists with an industrial engineering background to continue this work (Carlson, 1989).

4. Discussion

These case studies illustrate several improvements in ergonomics and productivity. In some cases it is, however, difficult to quantify exactly how much of the productivity improvements should be attributed to ergonomics, since there were several simultaneous fine tunings of the production technology which also contributed to improvements. To isolate the effects of ergonomics, one should ideally perform controlled studies with two identical manufacturing organizations, where one is subjected to ergonomic redesign, and the other is used for control. Thereby it would be feasible to draw firm conclusions about the impact of ergonomic redesign as opposed to other simultaneous changes in the pro-
duction process, organizational climate, and so forth.

Campbell and Stanley (1963) described several types of experimental design that can be used in a field setting to distinguish the impact of such factors. In our case, controlled studies for comparison were impossible to organize. Although this is unsatisfactory from a scientific perspective, it is a common problem in industry, since it is difficult to find parallel organizations of this magnitude in manufacturing using the same type of machinery and the same type of tasks. We were hence restricted to selective evaluation methods without the possibility of statistical significance testing. For example, at IBM Austin, twenty-six managers and engineers were interviewed after the conclusion of the studies. They agreed that approximately half of the savings could be attributed to ergonomics, while the remaining half were attributed to other improvements. They were extremely positive about the ergonomics improvements and particularly the effects of the increased illumination levels for visual inspection.

Although it is difficult to credit improvements in productivity to any specific source, the manufacturing management who participated in these studies agreed that the ergonomic changes acted as a catalyst for other improvements. Several other manufacturing areas claimed benefits from the ergonomic redesigns since it improved the quality of products coming into their areas. Suggestions for ergonomic improvements were also submitted to these departments and ergonomic improvements were carried out.

Management at IBM Austin recognized that employee involvement was important to success. Employees were highly enthusiastic, and in each instance absenteeism was reduced one or two percentage points. We regard this as an indication that job satisfaction improved substantially. These intangible benefits are easy to surmise from comparison of “before” and “after” photographs, but are more difficult to quantify in terms of cost savings.

Ergonomics in industry is nothing new (IBM, 1981; Eastman Kodak, 1983). There are many examples of successful implementations to improve biomechanics, materials handling and problems that concentrate on environmental factors such as noise and climate. However, what is fairly new is implementation of ergonomics into the manufacturing process with the specific goal of improving productivity. This must consider additional factors such as information flow and feedback between operators and machines, and requires a thorough understanding of the manufacturing process (e.g., Burri and Helander, 1991b).

On the surface it may seem that the suggested list of recommendations does nothing but address traditional ergonomics approach to industry. However, in our four case studies, it was crucial to consider the manufacturing process and alternatives for process layout and types of equipment available. This requires engineering as well as ergonomics analyses, something that is not easy to carry out unless the analyst has a background in both engineering and ergonomics. During the last ten years there has been an increasing number of human factors specialists graduating from programs of industrial engineering. Such background is desired. Medical doctors, physiotherapists, and occupational nurses would be less appropriate, unless they thoroughly understand the manufacturing part of the problem. Also, individuals with a background in management would not necessarily have the desired prerequisites (Burri and Helander, 1991b).

DeKeyser (1992) emphasized that ergonomic field studies are necessary to validate methods developed in the laboratory. Field studies are particularly important for evaluation of productivity, since there are organizational and motivational parameters that cannot be replicated in the laboratory. In our case studies we had clear expectations of what kind of ergonomic measures would be successful, and we also predicted improvements in productivity. These expectations were based on our previous experience as well as empirical data from laboratory studies. The problem is then to generalize from the present study to other contexts. This would require a description of the work activities, decision making and information processing (Rasmussen, 1992). In our case this may be fairly easy, because of the repetitive, fairly procedural work performed. What is more difficult is the description of the manage-
ment structure, competence of workers, and allocation of tasks and decision roles between computers and employees. For this purpose we must develop a taxonomy that can be used for classification of ergonomic improvement.

Parsons (1992) referred to the famous Hawthorne studies performed by Roethlisberger around 1935. These studies (although scientifically flawed) pointed to the potentially beneficial effects of ergonomic improvements in manufacturing. To our knowledge there has been no subsequent ergonomics research program of experimentation and observation in an industrial plant with quite the same breadth and duration or as pioneering and influential as the Hawthorne research (despite the flawed results). Parsons poses that “something is wrong with American industry that more than five decades have passed without a human factors research enterprise equivalent in originality, candor and scope to investigate the impacts of new technology and automation”. This requires controlled experimentation, testing of hypotheses, and further development of the framework suggested in Fig. 1.

Based on the enthusiasm of the individuals involved in the present studies, and the encouraging results, we feel it is time to introduce ergonomic studies of productivity. With a dual concern for the operator and the manufacturing process, it is possible to increase productivity and quality of manufacturing as well as operator comfort and health. More research is needed to understand the potential for improvements in productivity, and to develop a task taxonomy for classification of field studies.

In the business world, ergonomics must be considered another tool for improving work environments for people and overall productivity for the company. The benefits derived from IBM's ergonomics programs have grown steadily, from the 1980 $60,000 productivity savings in Boulder, described in the first case study, to the $7,375,000 savings at IBM, Austin in 1988. In addition to these activities, there have been several projects at other plant locations to improve ergonomics and productivity. We estimate that over the past ten years ergonomics measures have generated savings of approximately $130 million. Management and employees should continue to work together to capture these dual opportunities for employee comfort and improvements in productivity.

Acknowledgement

We appreciate the help of Ms. Patricia Brock in typing and editing this paper.

References


Cadigan, M., 1988. Personal communication. IBM Corporation, Austin, TX.


Carlson, J., 1989. Personal communication. IBM Corporation. Austin, TX.


Grossmith, E., 1990. Personal communication. IBM Corporation, San Jose, CA.


Lakoski, T., 1988. Personal communication. IBM Corporation, Austin, TX.
Short, M., 1981. Improvement of Workstations for Subassemblies for Copier Machines. IBM Corporation, Department of Industrial Engineering and Manufacturing Support, Boulder, CO.