

TIME AND MOTION ANALYSES OF MANUAL SORTING PROCEDURES AT MATERIALS RECOVERY FACILITIES

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ABSTRACT

In an effort to analyze discrete manual sorting activities on processing lines, time and motion studies were recently performed at two Materials Recovery Facilities. Using automatic and manual sorting techniques, glass and plastic bottles and steel and aluminum cans are processed at the facilities. The number of motions per minute per sorter was studied, as well as ergonomic characteristics of the sorting procedure itself. By performing numerous studies at each sorting position, information was collected which has affected process design, line staffing and employee training. Sorting line design improvements, which were made as a direct result of the studies, have contributed to the maximization of product quality at the facilities while minimizing the number of employees required to perform sorting activities.

NOMENCLATURE

Furnace-Ready

Cullet = Glass which has been processed such that it can be sent directly to the glass furnace without any further processing by the glass mill.

HDPE = High Density Polyethylene.

MRF = Materials Recovery Facility.

Negative

Sorting = Material which is processed by exception or default; material which remains on a conveyor belt after removing all other items.

PET = Polyethylene Terephthalate.

Positive

Sorting = Manually or physically removing items from a stream of material on a conveyor belt and placing them in a manner for further processing.

INTRODUCTION

The enormous increase in recycling activity which has occurred over the last decade has presented a challenge to the designers of facilities which process recyclables. Successful planning and design of these plants, commonly known as Materials Recovery Facilities or MRFs, has to incorporate the constant technological advances in recycling equipment in conjunction with the results of various experiments and studies performed on existing processes.

The current state-of-the-art MRF interfaces an increasing amount of automatic processing equipment with manual sorting activities in order to cost effectively process commingled glass, plastics, steel and aluminum into marketable products. A great wealth of

knowledge can be gained to aid MRF design by analyzing each component of the processing system.

This paper focuses on the human element of the process and how the nature of manual sorting activities influence the design of a MRF. The method of analysis of the human element was the performance of numerous traditional time and motion studies at each position on the commingled material sorting lines at two separate MRFs.

There were six primary goals associated with the performance of the tests:

(a) The determination of the number of motions per minute per sorter for each particular material.

(b) How the number of motions per minute varies by position on the sorting line.

(c) The determination of worker under-utilization or over-utilization to improve line staffing methods.

(d) How processed material quality is affected by altering the responsibilities and staffing of sorters on a sorting line.

(e) The effects of training and instruction.

(f) The determination of improvements to be made with regard to ergonomics, and material flow quantities.

The time and motion studies were performed on the commingled processing systems at a 10 ton/hr rated MRF in Cape May County, New Jersey, and a 6 ton/hr rated MRF in Syracuse, New York.

PROCESS DESCRIPTION

Cape May MRF

Commingled materials composed of glass, plastics, aluminum, steel cans and a certain amount of trash enter the process from an infeed hopper in the tipping area by way of a corrugated sidewall conveyor belt known herein as a "box belt" conveyor. The automatic sorting process indicated on Fig. 1 includes electromagnetic separators, vibrating grizzly separators, and air separators which separate the incoming commingled material into streams of tin plated steel cans, broken glass, aluminum and plastics, and whole bottles. The broken glass and steel can streams continue to further automatic processing while the aluminum, plastics, and whole glass bottle streams are manually separated on the sorting lines using both positive and negative sorting techniques.

On the Plastics/Aluminum Sorting line, plastic bottles are manually removed from the stream, i.e., positively sorted, and separated into three grades: Natural High Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), and colored HDPE. Natural HDPE

consists of various sizes of milk and water jugs. PET consists of 1-, 2-, and 3-L soda bottles and colored HDPE consists of detergent bottles, motor oil bottles, bleach bottles and the like. Each grade of plastic is subsequently tossed across the conveyor belt into a storage bin. The storage bins feed a baler which bales each grade of plastic for ease of storage and shipment. Pieces of trash which were transferred to the line with the aluminum and plastic are also positively sorted. These items are deposited into the chutes indicated on Fig. 1. The remaining material on the line which is allowed to pass to the next stage of operations, i.e., negatively sorted, is aluminum. Aluminum consists primarily of aluminum beverage cans, but also contains aluminum foil. These materials are transferred to a densifier which compacts the aluminum into "briquettes". For the time and motion studies, four sorters were utilized on the plastic/aluminum sorting line and are indicated on Fig. 1 as numbers one through four (circled). They will be referred to in this paper according to their position number on the line. Sorter number one handles Natural HDPE, the second sorter handles PET, and sorters three and four handle colored HDPE and trash.

The determination is made during the design stage as to what material will be positively sorted and what material will be negatively sorted. The normal layout of a mechanical sorting conveyor allows for only one material to be negatively sorted and multiple material to be positively sorted. The positively sorted material can be pulled and placed in bins, chutes and hoppers while the negatively sorted material falls off the end of the conveyor. The most efficient design provides that the material which requires the highest number of sorting motions, or is the most difficult to remove from the stream, be negatively sorted. Manpower efficiency is maximized because a minimum number of people can be used to sort a greater amount of material in this manner.

Whole bottle glass, some pieces of broken glass and a nominal amount of aluminum, plastics and trash are transferred from the automatic process to the glass sorting conveyor line. Any trash, plastics or aluminum which reach the line are positively sorted at the "lead man" position and deposited into the chutes. The remaining glass stream made up of flint (clear), amber and green, is manually sorted by color. Amber and green glass are positively sorted onto the adjacent sections of the sort conveyor indicated on Fig. 1. Since a majority of the glass is flint, it is negatively sorted. The sorters identified as one, two and three on the figure are responsible for positively sorting whole bottles, broken bottles, and any remaining trash, respectively. After all

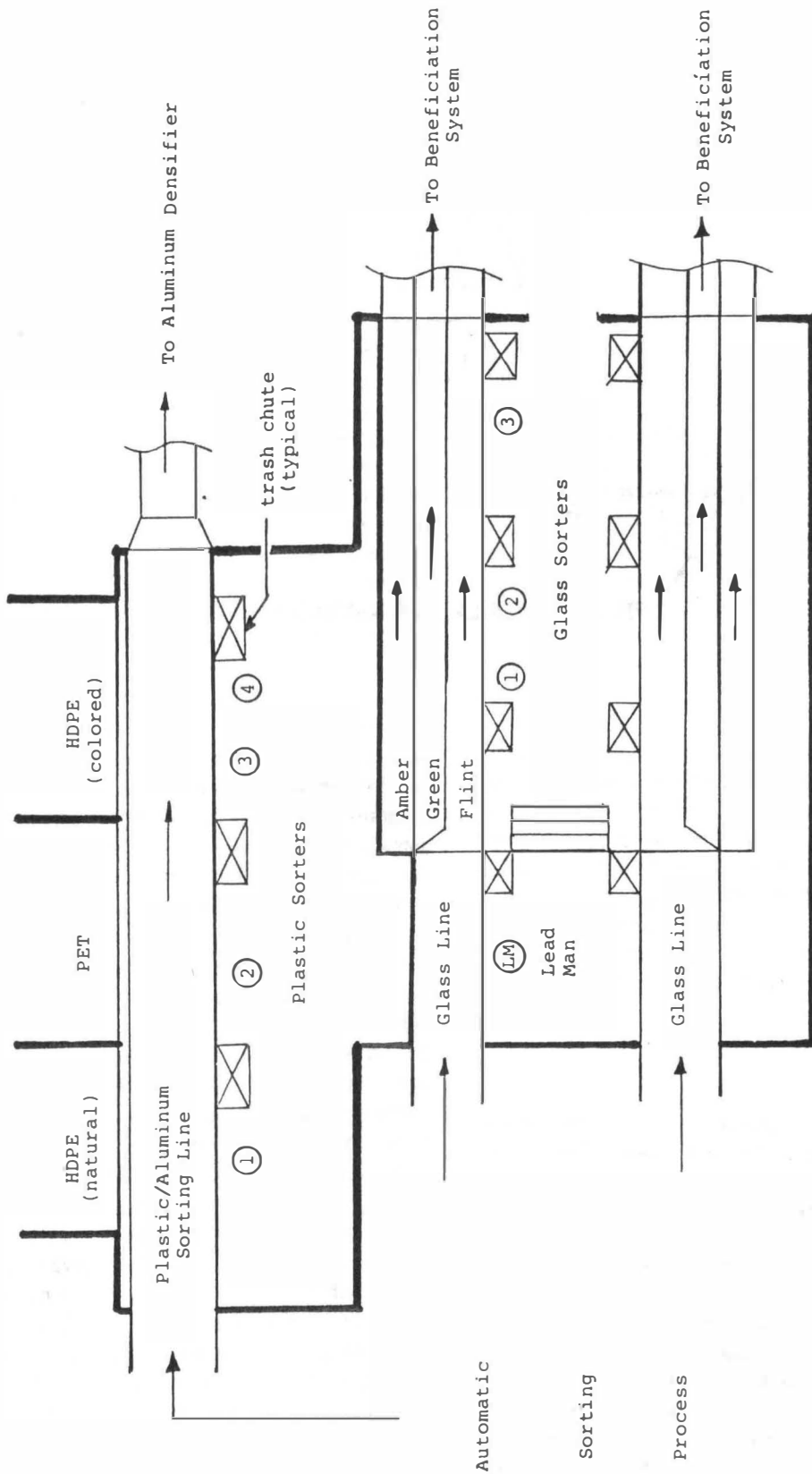


FIG. 1 SORTER LAYOUT — CAPE MAY

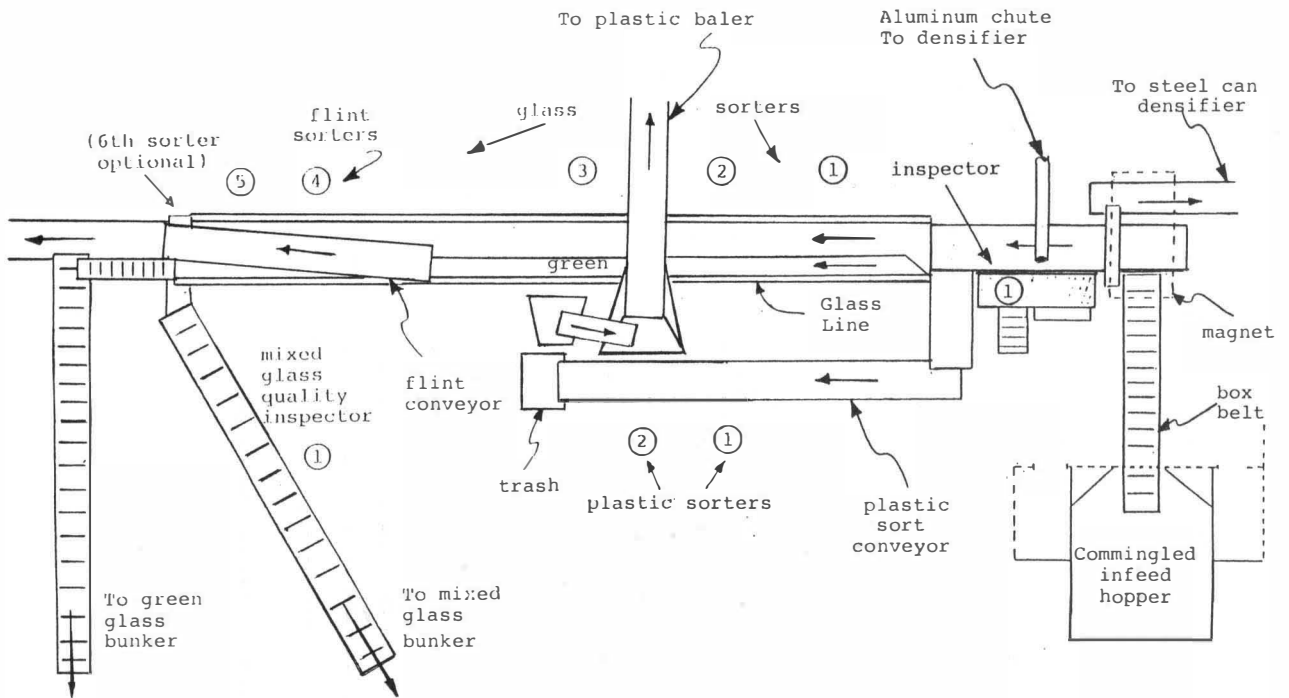


FIG. 2 SORTER LAYOUT — SYRACUSE

impurities have been removed, and the glass sorted by color, each color stream is sent through a beneficiation system which produces furnace-ready cullet. As indicated on Fig. 1, there are two separate glass sorting lines. In the interest of time during testing, it was assumed that as long as a sufficient number of studies were taken on each of the four sorting positions, only the sorters on one of the two glass lines would need to be observed. The results discussed later in this paper were extracted from the studies taken on only the sorters indicated on Fig. 1.

Syracuse MRF

The commingled sorting system used in the Syracuse MRF is shown on Fig. 2. Through a less sophisticated system than employed in Cape May, commingled materials composed of glass, plastics, aluminum, steel cans and a certain amount of trash enter the process from an infeed hopper in the tipping area by way of a box belt. The steel cans are first removed using an electromagnetic separator and are transferred to a densifier. The material is then sent through an inspection station where the inspector manually removes a percentage of the aluminum cans and places them into the chute indicated on the figure. The inspector is also responsible for pulling off large pieces of trash and monitoring the

flow of materials to the sorting lines. The remaining aluminum and plastics are transferred to the plastic sort conveyor by way of an air stream which separates light material from heavy material. The remaining glass passes onto the glass line. Five sorters on the glass line, indicated on the figure as numbers one through five (circled), positively sort material in the following manner. Sorter number one positively sorts green and brown glass. Green glass is placed onto the adjacent conveyor section indicated on Fig. 2, and brown glass is placed in barrels next to the sorter to be later manually transferred downstream. Sorter number two pulls any aluminum or steel which reached the glass line. These items are placed in barrels next to the sorter and later returned to the proper area in the plant. The third sorter removes any plastic bottles and tosses them into the hopper located on the opposite side of the belt. The fourth and fifth sorters positively sort flint glass bottles to a smaller conveyor which is elevated and slightly skewed above the sort conveyor. All remaining small pieces of broken glass are negatively sorted and are transferred to a conveyor which feeds the mixed glass storage bunker. The mixed glass quality inspector removes any remaining trash from the mixed glass stream. The remaining three colors of glass are conveyed to individual storage bunkers for shipment.

There are two sorters on the plastics line indicated as sorters one and two on the figure. Each sorter is responsible for pulling all types of plastic bottles from the line. Sorter number two has the additional responsibility of removing any aluminum and steel cans which may have reached the plastic line. Trash is negatively sorted on the plastics line due to the amount and piece size and is continuously collected in a 1 cu yd box at the end of the conveyor belt.

TESTING PROCEDURES

While evaluating under what conditions to perform the tests, it was decided that the most benefit would be gained by performing the tests during normal daily operations. It was also felt that observing the sorters during the first shift would be beneficial because they are the people who have had the most experience. As is the case with most jobs, there is a learning curve associated with the manual sorting process. Generally, as new people are hired at the plants, they are placed on the second shift, then over time as their experience grows, they are gradually moved to the first shift. It did not seem sensible to test the sorters who had not yet had sufficient experience on the line.

The box belts feeding the systems ran close to maximum capacity throughout the tests, just as they would on the average busy day. Sorting activity was observed over 10-min blocks of time using a stop watch and data sheets. Each 10-min block was divided into 1-min increments during which all sorting motions were counted and recorded by minute. Each study was performed one position at a time. There were a number of other observations and analyses which occurred during each study which included:

- (a) Overall responsibilities by position.
- (b) Nature of the flow of materials, i.e., surging of material versus nonsurges.
- (c) Number of motions per minute.
- (d) Amount or weight of material manually sorted per minute.
- (e) Percentage of one-hand to two-hand motions.
- (f) Sorter performance during surges and the effect of burden depth.
- (g) Sorter performance during nonsurges.
- (h) Recommendations for design, staffing and training improvements.

What resulted was 5–10 studies of each sorting position on the systems in both plants. The positions which seemed to have a higher degree of variance in the number of motions per minute and the positions which appeared to offer the most information were studied

more often than the positions which were consistently not busy.

GENERAL OBSERVATIONS

In addition to the numerous results which are outlined in the Results Section of this paper, there were a number of observations which were made while the studies were being performed.

Material Flow

While recording the events of each study, it was important to identify from time to time the material flow on the conveyors. The speed at which people perform sorting activities is not only dependent on the individual speed at which they themselves are capable of working, but also on the amount and composition of material that is available to sort. Material does not always flow at a constant rate throughout the process. Sometimes a large amount of plastics or glass will enter the process, causing what is known as surging. Surging occurs as a direct result of the way the material enters the system. The various types of material which make up the commingled stream are never evenly distributed throughout the stream, and when more of one type of material is present in the system, surging of that material will occur. Due to the large difference in densities between the two materials, glass and plastic surges usually oppose one another. Periods of time when a small amount of a certain type of material passes through the system are known as nonsurges or lull periods. Surge and nonsurge periods do not usually last for extended periods of time. The studies showed that glass and plastics surged about 25–30% of the time and were generally short in duration. Since it is a natural operational occurrence, it was important to the overall analysis to note how the sorters reacted to surging.

Sorter Performance During Surges

The study indicated that certain positions on the sorting line were more sensitive to surges of material than other positions. It was usually the first one or two sorters on a sort line whose performance increased dramatically during surges, although during heavy surges, all sorters' activity on a line increased. Exact figures on this can be found in the next section. Burden depth, or the depth of the material on a conveyor through which a sorter must sort, is the main indicator of a surge. There were times when the burden depth was such that the sorting line had to be briefly slowed

down or stopped in order that the sorters could continue to sort efficiently.

One-Hand and Two-Hand Motions

Another important observation was the measurement of how busy the sorters were as they were sorting. When the material flow was at a point where only one hand was required to remove material from a belt, the sorter usually opted to adjust his work load to this level. This was referred to as a "one-hand motion". The sorters who were the first (i.e., upstream of the others) sorters of a particular material on a line, such as the clear glass sorters (four and five) on the Syracuse glass line, worked at this level only 25% of the time, while the sorters toward the end of the lines worked at this level up to 90% of the time. "Two-hand motions" refers to when both hands are required to keep up with the level of material on a line. Two-hand motions, whether simultaneous or consecutive, were common 91% of the time for the first sorter on the Cape May glass line. As expected, the rate of two-hand motions increased throughout the systems as surging increased.

TESTING RESULTS

Figures 3-6 indicate, in graph form, the average number of motions per minute per sorter for each of the four sorting lines studied during the tests. In side to side comparisons of the two pairs of sorting systems, it must be remembered that there were major differences in the responsibilities and placement of sorters between the Cape May and Syracuse MRFs, most notably on the glass lines, which explains the obvious glass line inverse relationship.

Motions Per Minute

By performing the studies we were able to determine the average number of motions per minute per sorter at each sorting position in the systems. This is a very important piece of information because we generally know in advance what the expected flow quantities of each material will be at a facility that is in the design stage. Combining that information with equipment efficiencies and the knowledge of how much material can be sorted by the average trained sorter, an efficient sorting line can be designed that will accommodate the proper number of sorters. Each of these design considerations play an important role in the design of a MRF. For instance, it was determined at the Cape May Facility (Fig. 3) that the lead man position makes

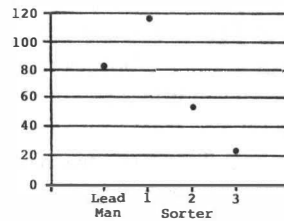


FIG. 3 GLASS LINE — CAPE MAY

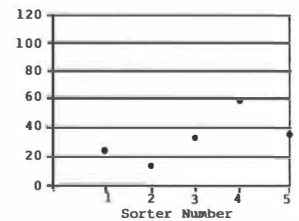


FIG. 4 FIG. 4 GLASS LINE — SYRACUSE

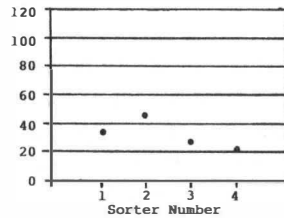


FIG. 5 PLASTIC LINE — CAPE MAY

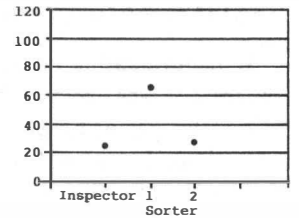


FIG. 6 PLASTIC LINE — SYRACUSE

82 motions per minute, approximately 5.7 lb of plastics and aluminum, and sorter number one on the glass line makes 118 motions per minute, which correlates to approximately 60 lb of whole glass per minute. Sorter number two makes 51 motions per minute for whole and broken glass, approximately 28 lb, and the third sorter makes 23 motions per minute, approximately one-half pound of trash. Given an assumed incoming mix for a proposed facility which contains twice the amount of glass but the same amount of trash as Cape May, combined with known equipment efficiencies, the glass line could be designed to accommodate twice the number of glass sorters but still one trash sorter. There are, of course, other variables which figure into the decision process, such as new technologies or improved equipment efficiencies, but as long as the human element remains an integral part of the process, knowledge of human performance in this fashion is invaluable.

Variance in Motions by Position

Another goal of these studies was to analyze the degree of variation of sorting motions between sorters on the same sorting line. As can be seen on the graphs, each sorting line possessed some degree of variance. Note the difference between sorters four and five on the Syracuse glass line (Fig. 4) and the difference between sorters one and two on the Syracuse plastic line (Fig. 6). The degree of variance in sorting motions can be attributed to the first sorter in each case performing to

his or her maximum potential, thereby leaving a much smaller amount of material to be sorted by the following person. The fourth sorter on the Syracuse glass line made an average of 59 motions per minute, or 30 lb of clear glass, permitting the fifth sorter to make 36 motions per minute, or 15 lb of clear glass. The first sorter on the Syracuse plastic line made an average of 63 motions, 11 lb/min, and the second sorter made 20 motions, or 3 lb/min. It is a function of sorter performance combined with the availability of material to sort, and it is a difficult phenomenon to alter from a design standpoint. There are generally two ways to "smooth out" the workload between the sorters or "line balance" the sorting lines. The first method is to give the sorter with the lesser workload additional responsibilities, which will be discussed further in this paper. The second, and in some circumstances more favorable option, is to periodically alternate the position of the two sorters over the course of the work day. By alternating the two positions in each case, it helped eliminate personal fatigue of the first sorter and boredom and distraction of the second sorter.

Line Staffing

The results of the study provided information about sorter utilization and the existence of under-staffing or over-staffing of sorters on each line. The ideal sorting system is staffed with enough sorters so that the line is capable of handling surges of material, but not with so many sorters that some are idle during nonsurges or moderate material flow. Certain sorting positions were actually eliminated because the capability was there to combine or absorb responsibilities of two semi-idle positions. Such was the case with sorters number one and two on the Syracuse glass line (Fig. 4). Their responsibilities were combined into one position which reduced operational costs. In another instance, the third sorter on the Cape May glass line was given the responsibility of inspecting both glass lines, thus eliminating another sorting position. This was possible because the back-to-back design of the glass lines (see Fig. 1) allows for one sorter to move back and forth between the lines. This again is one of the many ergonomic design considerations that go into the design of a MRF. If the design was different, such as separate sorting rooms or perpendicular conveyor design, this would not have been possible. In our studies, we were not able to find a position where a sorter was over-utilized for any great length of time. During surges, if a sorter was extremely busy, such as the first sorter on the Cape May glass line, the sorter behind him would increase his responsibility to make up for whatever the first

sorter could not handle. Generally surging did not last for extended periods of time, as previously discussed. When there were surges, everyone's activity on the line increased until the surge passed. By utilizing surge hoppers and variable belt speed drives we have designed systems so that surging and lull periods can be smoothed-out to as great extent as possible. It is impossible, however, to fully eliminate these situations. It is under these conditions where the human factor must be capable of finishing the job.

Material Quality

An unexpected result which came out of the studies was that material quality actually improved during times when the sorters were the busiest. This was an observed result. We felt this could be attributed to the lack of boredom that occurs when working at one's full potential. During slow times, many sorters could not leave their stations even to clean their area because there was some small amount of material on the belt that needed to be sorted. Boredom begins to occur, and with that they become easily distracted. When the intense concentration is required during moderately heavy material flows, the sorters tended to perform better. The workers in general seemed to enjoy the challenges presented to them during surges and we feel this is the reason quality improved.

Training and Instruction

Prior to these tests, there was no formal training program established at the facilities. Normally, new employees were placed on the line and briefly shown what material to sort. They usually had to rely on the experience of other sorters by watching them sort as they worked. Many observations were made throughout the studies that indicated the need for a formal training program. Some sorters expressed confusion when faced with items that were unfamiliar to them such as ceramics, PVC, and plastic film. Marketing specifications require that certain types of glass, such as plate glass and ceramics, be removed from the glass stream in order to be marketed as furnace-ready cullet. Each type of material processed at the facilities has similar marketing requirements. As a result of the studies performed at the plants, an intensive training program has been set up whereby all plant employees learn these marketing requirements and learn hands-on the proper ways to sort recyclables.

Design Improvements

There were many design improvements that were recommended on the Syracuse processing system. Most of the negative observations which were made in Syracuse were a direct result of the design. Some of the improvements were (see Fig. 2):

(a) The opening of the aluminum chute at the inspection station was too narrow, approximately 8 in., and cans had to be placed into the chute with a certain degree of accuracy. This took a great deal of time and also detracted from the inspector's other duties. The recommendation was to build a small hopper, 3-ft wide by 3-ft long, placed directly across the conveyor, so that the inspector could easily toss aluminum cans into it.

(b) The air sorter operated at an efficiency which allowed up to 30% of aluminum and plastic to reach the glass line. This alone was the reason that sorter number three was stationed on the glass line. An improved air sorting system would allow that position to be absorbed by another, such as sorter number 2. The costs of improving the air sorter would most likely be offset by the decrease in operational costs which would occur as a result of eliminating a sorter.

(c) A sturdy platform needed to be constructed to elevate the plastic sorters. The plastic sort conveyor increased at an angle of approximately 5 deg., from 4 ft at station one to 5 ft at the discharge end of the belt which is 12 ft long. A short person had a very hard time sorting material efficiently, so a 2-ft platform placed toward the end of the line was recommended as an ergonomic design improvement to help the sorting process.

(d) The elevated flint glass conveyor was plagued with problems. It was too short, approximately 9 ft, for more than two sorters to do this job comfortably and the width of the conveyor, 12 in., was such that it would often overload during surges of glass. There was also no skirting on the conveyor so glass was spilling over the edge as it was being sorted. Recommendations were made to add 6–8 in. of skirting, widen the conveyor by 4 in., and lengthen the conveyor by 5 ft to allow up to three sorters at one time, when necessary, to properly sort the material with no spillage.

At Cape May there were very few recommended design changes because MRF design experience had grown, just as the industry had grown over a period of about 3 years. Most of the recommendations pertained to the staffing and training issues discussed previously.

CONCLUSION

A great deal of information was learned about each system during the course of the analyses. The most important step in the entire process was being able to properly convey the data that was collected, and the observations and recommendations that were made to the appropriate personnel in operations and design. In the time since the studies were performed, a number of changes were made due to the results which have in many ways improved the design process, the training process and operations. It is one of the goals of the Human Resources and Design departments to continue to perform such tests at each new facility, as well as retest the existing facilities in an effort to further improve the efficiencies of the recycling systems.