CONFERENCE PAPER

A Practical Approach to Automatic Production

by D. J. Clough, J. W. Abrams, R. W. P. Anderson

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FOREWORD

The three authors of this paper are members of Systems Engineering Associates Limited, Toronto. In addition, Dr. Abrams and Mr. Clough are Associate Professors, and Mr. Anderson an Assistant Professor, at the University of Toronto.

The authors are among a group of specialists commissioned jointly by the Economic Council of Canada and the Ontario Economic Council to undertake special studies and prepare papers, such as this one, for the Conference on Productivity Through New Technology, held at Ryerson Polytechnical Institute, Toronto, May 27 and 28, 1965.

The purpose of the Conference was to inform senior executives of small- and medium-sized businesses about the practical application of the new management, production and handling concepts, techniques and tools available to them, including the use of computers and automatic production equipment. The Conference participants -- approximately 300 businessmen -- were afforded the maximum opportunity of informal discussion with the authors of the papers.

In publishing these Conference papers, the Economic Council of Canada hopes that the material will be useful to others, and perhaps serve as the basis of similar conferences. A list of the studies being published, with a brief description of each, will be found at the end of this document. The views in these papers remain the responsibility of the authors.

CONTENTS

1. INTRODUCTION

This paper focuses attention on some of the thornier practical problems which small Canadian manufacturing companies face as a result of the technological advances that are now widely available. The objective is to give small companies some indication of the major factors of importance in mechanization.

In preparing the paper, the authors made a limited field investigation of representative firms in three general areas of manufacturing: a primary manufacturing industry typified by wood furniture production, a secondary manufacturing industry for which the light electrical area was investigated, and a service industry represented by laundering, dry cleaning and rug cleaning. The machines and environments found in these investigations are reported here, with some supporting material from reports of other studies and from recent publications.

No process industries were examined, and the company or division size was limited in general to those employing fewer than 300 persons (see Appendix III).

The report which follows is comprised of a definition of automation and mechanization, a discussion of the ways in which it was found that automation is approached, an outline of the more important technological, economic, and other factors which must be considered as mechanization is implemented, and certain observations and conclusions arising from the investigation.

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2. WHAT IS AUTOMATION?

The word automation, which was coined in 1949 and came into general usage in the early 1950's, is evidently a contraction of automatization or automatic operation. Webster's Dictionary defines automation in a straightforward way as follows:

> "... in manufacturing, a system or method in which many or all of the processes of production, movement, and inspection of parts and materials are automatically performed or controlled by self-operating machinery, electronic devices, etc."

In recent years the word automation has been used in a variety of ways by managers, union leaders, politicians, and newspaper editors, in reference not only to the production of goods but also to the performance of services and specifically to the processing of information. To avoid problems of communication, in this paper we generally use the word mechanization instead of automation. Then we can talk about the level of mechanization in terms of the human energy-producing and information-producing attributes that are replaced by machines. And we can talk about the degree of mechanization in terms of the ratio of automatic machine operations to total operations in a particular production process. Appendix I contains a key to the six levels of automation likely to be encountered, and explains the determination of degree. Appendix II is a Glossary of Production Terms.

Further we shall talk about four types of automatic equipment which can be introduced into a manufacturing process, as follows:

Type 1. The small, limited purpose, automatic device which can be introduced into a manufacturing system as an adjunct to an existing machine, or to replace some small hand operation and speed-up what was previously a bottleneck. Where such devices can be installed they offer a relatively low-cost method of improving efficiency.

Type 2. The automatic or semi-automatic machine which can be introduced into a production line to perform operations with greater speed and accuracy than the machines replaced. They may also be required to undertake operations which could not previously be performed on the older machines.

Type 3. The introduction of an entire new production process, consisting of several integrated machines, to replace an existing process.

Type 4. The complete mechanization of a whole plant by the introduction of an integrated system of automated machines and mechanized production control.

3. HOW TO GO ABOUT MECHANIZATION

The question of what and how to mechanize is a vexing one because its answer depends upon a great many variables. The decision to examine possibilities for mechanization is found to be forced partly by external competitive pressures, and partly by internal pressures to produce more economically or to expand production facilities.

Piecemeal vs. integrated mechanization

In any decision involving the purchase of new equipment, two main approaches to mechanization can be considered: integrated mechanization or piecemeal mechanization.*

If mechanization is to be integrated, the complete system of production within a plant (or a subsystem for an isolated product line) must be considered. This is not to suggest that it is necessary to install a completely integrated system in one pass, but that the complete system must be planned to grow as a smoothly working, matched set of machines, laid out to take best advantage of the space available and of the fixed facilities such as loading bays, raw material storages, offices and the like. Once the system is planned to operate essentially as a single complex machine receiving raw material at one end and producing finished goods at the other, the question of how to implement the plan may be tackled.

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* Type 1 mechanization is fundamentally piecemeal by nature. It is only applicable, by definition, to existing bottlenecks or limited areas so that problems of imbalance do not arise. Similarly, types 3 and 4 mechanization are by nature integrated.

Implementation must depend to a large degree upon the speed with which it may go forward. If funds are available, and their expenditure has been justified, the integrated system may be completely installed in one grand re-organization during which production is halted, and subsequent to which there will likely be a period of adjustment, both of machines and operators, where production will be low and rejects and reworking will be high. If a stoppage of production cannot be tolerated, if funding is not adequate, or if extra time is required for experimentation and learning, installation of the integrated system may be carried forward more slowly. In this case there must still be careful long-range planning based upon good sales forecasts, availability of economic and human resources, and ultimate layout of plant. Then gradual mechanization may be carried out according to a priority listing of requirements, with as little as possible duplication of effort, relocation of new machines, dislocation of personnel, etc.

Two cases of gradual introduction of reasonably integrated, though far from fully automatic, systems were observed in the electrical industries. In one case type 2 introduction of automatic machines for stator coil winding was proceeding, one machine having been installed, operated for some time and proved successful, thus encouraging the purchase of sufficient of these devices to carry all of the standard production of the plant. The same general approach of making haste slowly was evident in several companies observed.

What then is the fundamental difference between piecemeal mechanization and gradual integrated mechanization? The difference lies in the aim of the process. With integrated mechanization one aims at a set of machines matched to each other in capacity and capability, all having mutually consistent accuracy and production capacities. These machines, when properly adjusted, will work together harmoniously, requiring the minimum of operator intervention. There may even be some automatic feedback of information from one part of the line to another for control of dimensions or of line speed. On the other hand, with piecemeal mechanization one does not expect the same degree of unity in the production system. The degree to which all machines are matched in accuracy and speed is likely to be lower. The number of operators will be greater, for there would normally be more non-mechanized operations interspersed among the mechanized ones. In piecemeal mechanization the explicit assumption is that economic prospects are considered to be insufficient to allow the attainment of a truly integrated system during the expected life of any new machines. Therefore, since the integrated system is unattainable, advantage will be taken of localized mechanization in those areas where its payoff is adequate and immediate. Examples of this procedure were also observed. As would be expected, processes sensitive to style changes were confined to types 1 and 2 introductions, and only in those insensitive to style or product line changes were introductions of type 3 found.

Examples of these latter introductions were found in the semi-automatic finishing of shirts after drying and up to band stapling in the laundry industry, or in a hand loaded but otherwise automatic cleaning and plating machine in the electrical industry.

Piecemeal mechanization was found to be initiated in many areas. Those most commonly thought of are - the areas of materials handling between machines, mechanization of the machining processes, and packaging. Areas not generally considered are those of assembly, inspection and testing. The decision on what to automate among these local areas becomes one of determining where the best immediate economy is to be found, and in this context the determination of best economy is not a simple job. Questions of stability of product line versus adaptability of machines, suitability of product in its present or a redesigned form for mechanical operations, and ease of matching existing machines and processes to new highly mechanized ones must all be weighed carefully before a final decision is made. It should be anticipated that any purchased machine will have to be modified in some way, either upon installation or early in its useful lifetime so that it will conform to the individual plant's requirements.

4. FACTORS TO CONSIDER

Technological and Production Management Factors

We have emphasized in the preceding section that no matter what kind of mechanization is contemplated, whether it be the mechanization of a complete manufacturing process or the purchase of a single semi-automatic machine, the impact upon the whole plant should be considered. In fact, not only must the physical plant be thought of, but also the product itself, the operators in the plant, the buyers of the product, and the management control aspects, all of which are affected by alterations in production methods. It is these factors which concern us in the design for mechanization.

In designing for a high degree of mechanization, a number of preliminary steps have to be taken. The following steps are found to be among the more important ones.

(1) Product simplification. A first step is to examine the product. Is it well designed for the mechanization proposed, or would mechanization be more effective if the product were to be simplified, or if some of the parts were redesigned? Mechanical handling equipment may be greatly simplified if parts can be designed so that they can be easily picked up and carried mechanically. Automatic machinery can be more profitably used if product simplification is carried out first. In the electrical industry, redesign of product, not invariably for purposes of mechanization, has led to a number of improvements. The assembly of

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switches has been facilitated by so designing that all parts are inserted from one side of the moulded housing. A number of progressive dies doing up to five operations reduce handling and increase safety. In woodworking, design changes have been forced by the adoption of new machinery.

(2) Standardization. Standardization of parts from product to product should be studied thoroughly. Standardization has been observed to spread the benefits of mechanization more uniformly across the company's product line and to reduce the likelihood of a heavy imbalance in production operations. For example, superficial changes allow a standardized appliance body to satisfy a number of demands, and thus allow the use of a simple set of dies and assembly jigs in the production. A small number of standardized lamination patterns are used in fractional horsepower motors, allowing efficient use of an automatic press, though the number of laminations used in a unit is more variable, and so less complete mechanization of other aspects of the production is feasible.

The extent to which standardization can be accomplished is related to the stability of product line. It is hardly necessary to point out that mechanization, however effective, is not going to make a profit on a product whose market is gone. This factor is found to be important not only in style-conscious industries, but also in light electrical equipment manufacture where the average time cycle for design change is of the order of 15 months. Any mechanization carried out must be either flexible or associated with a very stable product. Because of the small size of markets, flexibility is a necessity in Canadian industry both to accomodate new products as they are developed and for old products. Standardization of parts helps greatly to maintain flexibility.

(3) Method studies. Methods must be studied before mechanization. Certainly they will change as a plant becomes more mechanized, but it is only by searching study in the initial phases of the design that the effectiveness of a proposed mechanized process can be determined. Method studies provide the basis for make-or-buy decisions, and decision concerning materials, process design, plant layout, flow arrangement, and production planning. Method studies often disclose apparently insignificant areas in which small investment in the most elementary mechanization produces large payoffs; it is through them that areas for application of type 1 mechanization are revealed, for example, in a trivially simple device for avoiding open bars in motor rotors.

(4) Process design. Process design and layout of plant for smooth flow or easy storage of in-process inventory should be of primary concern. There is nothing more disturbing than owning a highly automatic machine that can only be utilized a small percentage of the time because of bottlenecks in other parts of the plant. Such cases were observed in several instances in wood furniture plants where new widebelt sanding machines were operating less than two days a week to meet all the production requirements. This resulted in an imbalance of in-process inventories and work loads. Similarly, machines and work stations should be so arranged and linked by materials handling equipment that

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fluctuations in product flow caused by rejects and reworking, or more serious disruptions caused by changes from one product to another, will not result in delays which may be propagated throughout the system.

(5) Transport and product flow. In the electrical industry, the great majority of materials transport seen in the visits was by tub or box, in all but very few cases, hand carried. Roller conveyors were used where tubs were heavy and in a few locations, belt conveyors were used in assembly. The outstanding feature of the conveyor assembly systems seen was the great reduction effected in in-process inventory with its attendant saving of floor space utilization. This reduction in in-process work tends to make good control of the process more essential, and in one line the schedule and operations were geared to the assembly conveyor, each foreman supplying the conveyor and planning and executing his own job for the uninterrupted flow of product at the assembly point. This means where production of from eight to thirty models during a week is scheduled, that supplying areas set their own lead times and rates to fit the schedule of the main assembly. All individual scheduling is thus done at the foreman level.

In the laundry and dry cleaning industry, mechanized transport is not extensively employed, chiefly because of the lack of sufficient volume to justify mechanical systems. One rug cleaning plant employed hand loaded automatic transfer equipment in its washing complex, the other used some manual, some mechanized transfer.

(6) Men in the man-machine system. The need for production planning staff must be assessed in advance as an essential part of an integrated production system, and the basic job descriptions for such a staff should be considered in advance. It is too late to start thinking about additional staff (and its costs) after the new equipment has been installed. This lesson had been learned the hard way in some plants visited.

In planning for mechanization, consideration should be given to preventive maintenance, human engineering, inspection and quality control, and operator rules and instruction, all of which require competent staff.

The maintenance situation changes with the introduction of new machinery. New machines may be more self sufficient in day-to-day service requirements, but the relatively large investment in them should be protected by a preventive maintenance plan. Further, the skills required to give good service and good operation of a complex machine generally necessitate an upgrading of maintenance personnel. In one manager's experience, the combination of electrical, electronic, mechanical, pneumatic and hydraulic systems in modern machines was changing his maintenance staff drastically. His best men were fitters who had attended three or more night courses in pneumatics, hydraulics and electronics.

The greater complexity of new machines should indicate their proper design in terms of human engineering, having controls which are both convenient and easy to operate without sacrificing "feel" where it is desirable. The environment (e.g. lighting, noise, heat, fumes) should be so designed that efficient work may be expected. In this connection some care should be taken in small detail to avoid a situation observed in which the placement of a worker's fan was such that dirt was blown onto the product, thus causing defects. Another situation was observed where equipment was not utilized because of inconveniences in its operation.

Human engineering considerations such as the choice of a suitable height for work tables, the convenient non-motion-wasting location of part bins, and the convenient placement of instruments that have to be read, may seem obvious, but they are often treated too casually. One major consideration that may be overlooked is the social-psychology of the factory. Workmen have certain psychological needs for activity that have to be satisfied on the job. In a level 1 application involving the testing of complex electro-pneumatic valves, test rigs have been designed to facilitate carrying out a series of inspections. In these rigs, single switches cause complete electrical or pneumatic tests to be carried out by controlling electric valves. It is found that while these rigs are mechanically very satisfactory, they are not so desirable from the operator's point of view. The checking job which previously required a fair degree of skill and operator manipulation is now considered to be lacking in sufficient operator intervention to maintain interest, yet is not so automatic that attention is not constantly required.

Where more complicated and faster machines are used, operators require a special kind of training.

The operator must be able to recognize that a machine is not operating properly and requires adjustment or maintenance. Operator skills change as mechanization advances, and the emphasis shifts from craft skills to mechanical skills and the ability to diagnose incipient faults. In designing for mechanization, the availability of machine operators and their training requirements must be carefully weighed.

(7) Specification of materials. Production processes should be viewed as starting in the material supplier's factory. In the light electrical industry this is done by specifying raw material most suitable for production, thus high quality sheet stock eliminates buffing before plating, special rolled shafting eliminates grinding. Trouble can be encountered, however, either through the purchase of new machines which demand a quality of raw material which may fetch a premium, or through the use of special material which demands better machines. One manufacturer discovered that the purchase of plated steel eliminated a troublesome plating operation but was found to require better control of welding, obtained only through new electronically controlled equipment.

The woodworking industry has run into the same sort of problem, where modern sanding equipment is necessary to deal with thinner veneers. Similarly, dry cleaners must constantly watch for new fabrics and other materials requiring new cleaning methods.

(8) Automatic operations. As a basic principle of automatic production, as many operations as possible should be carried out in one continuous process,

including machining, measuring, assembling, testing, and packaging operations. This is an ideal which was not observed in any field trip. The majority of introductions of mechanization were at type 1 or 2, but among these individual mechanisms or machines, a wide range of sophistication was observed.

In a number of cases, machine operations have replaced hand operations by highly trained workers. A good example of this is in the stator winding for small motors already mentioned, where a Lincoln winder with one operator replaces a number of skilled workers. (According to the classification in Appendix I, this would be a level 2 machine.) The hand operation involves form winding of motor coils, removal of coils from the form and temporary binding, transport of coils to assembly benches, insertion of coils into stator slots, and final forming of coil ends. All of these operations are eliminated by a single machine with one skilled operator. Setup time of this machine is relatively large, and its price is of the order of $25,000. Its success is evident, for the manufacturer is considering purchase of more of these machines to mechanize virtually all of his winding operations.

Motor endplates were machined on automatic Bertram lathes, for example, representing level 2, degree 4/6. (See the classification of Appendix I.) Here one operator is able to tend five machines, carrying out the loading and unloading operations and starting the cycle. The possibility of replacement of this process by die casting exists. Motor frames are rolled from plate, welded, and subsequently a spiggot is cut. There is a possible reduction in operations here if welding is done on an automatic machine where tolerances may be held closely enough to eliminate the post-weld machining. The use of bonding materials in rotor construction eliminates a shaft machining operation, though rotor truing, a level 2, degree 1/3 operation cannot be avoided easily.

Two small, fully automatic devices, level 3, degree 2/2, were noted. One was a magazine loaded device used for inserting a self-tapping screw into a small block of insulating material. It consisted primarily of a pneumatic screwdriver and transfer mechanism controlled by microswitch sensors. The second was a vibrating-hopper fed terminal forming machine. A significant point in connection with the first of these devices is the question of whether it is a tool or a machine, for tax purposes. The manufacturer claims the designation tool since it can only operate on a specific part of relatively short lived design.

In the service industry, the extent of automatic machining may be shown by the examples of shirt laundering, and rug and drapery cleaning establishments. Shirts are transferred by hand from location to location, but all processing is done by automatic equipment. Washing is done by a heavy duty washing machine with hot water provided by a large boiler. All phases of the washing operation are performed automatically in sequence in the same machine. Laundry is then hand transferred to an automatic drying machine located alongside.

Dry shirts are then hand-transferred to a four-stage ironing and folding complex. Machines in the

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complex are each hand-started but then undertake their operations automatically. In order: (1) Collars and cuffs are steam-pressed, (2) Sleeves are ironed, buttons fastened by hand, (3) Shirt body is pressed, buttons fastened by hand, (4) Shirt is folded and banded, band stapled by hand. The complex is run by one operator who transfers the shirts, does the hand operations, and starts each piece of equipment on its operating cycle. Capacity is of the order of 50-60 per hour. This is adequate to process the maximum day's order with none left over.

The automatic equipment is not flexible enough to process all shirts. The remainder are ironed in a less automatic complex of three pieces. The equipment is similar but requires hand manipulation. Folding is also done by hand.

For rugs, in one case processing is virtually automatic with component machines being fed by hand. A mixture of hand transfer and automatic transfer is employed. Because of the nature of the process it is not possible to inspect intermediate stages of cleaning and devote special attention to selected areas. The answer to this is either re-processing or hand-operated machine-assisted treatment of selected pieces. In this and other aspects automatic machines are inadequate to perform the function as well as can be done by careful hand treatment. High cost of non-automatic operation, however, precludes its general use.

In the second case, a new, modern plant with mostly new equipment was visited. Rug cleaning is performed by hand-fed equipment, but subsequent operations (including a re-wash cycle) are performed with automatic transfer, although the transfer rack is hand-loaded. The washing machine is set and controlled from a panel. Hand transfer is only employed to bring rugs to and from the washing complex. The final machine, the wrapper and roller, is semi-automatic, being hand set.

Again in drapery cleaning, the two plants used somewhat different approaches. In the first, drapery cleaning is fully mechanized with hand transfer. Multi-phase operation is combined in a single piece of equipment. Dry cleaning is similarly accomplished.

Drapery ironing and setting is done by a combination of operations of varying degrees of mechanization. All equipment requires hand loading, and material is transferred by hand. Processing equipment is of two types: (1) That which can give superior performance to hand processing with little gain in time, although operator time is probably somewhat reduced, and (2) That which gives performance similar or slightly superior to hand operation, but at a considerable gain in time. All draperies, however, require a modicum of hand attention. Part of this is required by the nature of drapery hooks, which must either be rubber-covered (by hand) or removed before processing. The total system is far from being fully automatic.

In the second plant, draperies are hand measured and hand transferred to two machines, which perform the washing and drying operations, and then hand transferred to the pressing operation. Pressing is done with manually controlled machines, and then the drapes are automatically transferred to the pleating machine.

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Although the process is automatic it requires hand loading and unloading. This would constitute a bottleneck except that one operator handles several machines simultaneously. Subsequent transfer to delivery racks is automatic.

The wood furniture industry yields the following four typical examples of the level and degree of mechanization being achieved at present:

In the first case, the recently acquired equipment includes a new 24 inch floating head planer and an undercut planer connected by a conveyor belt. This level 2 equipment cost $18,000 and allows two men to do about the same work that formerly required five men. A new $7,000 pair of level 2 tenon and mortise-making machines, for example, allows two unskilled workers in eight hours to do the work formerly done by one skilled and two unskilled workmen in thirty hours.

In the second case, the most recently acquired piece of equipment is an electronic core-stock gluing machine that cost about $30,000. This machine saves three or four men, increases production between 25% and 50%, and does a better gluing job. At present the machine cannot be utilized effectively at existing production levels, and it causes a huge buildup of stock in front of the much slower cutting operations that follow. This and other new machines have caused a "chain reaction" unbalancing of production and a need for additional new equipment and better production planning and control.

In the third case, some of the new equipment has been purchased specifically to improve quality and to facilitate the use of new materials and designs. For example, new wide-belt sanding machines are needed to give good dimensional control in the sanding of very thin walnut veneer. (The thickness of the imported walnut veneer has been reduced from 1/28 inch to 1/36 inch as a hardwood conservation measure imposed by the U.S. federal government.) A new router has been purchased to allow contour routing that no other Canadian competitor can duplicate at present. A 1955 model hot press gluing machine will soon have to be replaced, at a cost of $30,000, because of improvements in the gluing material that will permit faster cycle times.

It is interesting to note that the new equipment in this factory is representative of seven or eight countries. The young production manager has made himself a widely recognized authority on modern wood-working equipment, and has toured Europe in search of the best equipment available. Two of his chief selection criteria are quality of work produced and durability (freedom from excessive maintenance).

Finally, in the fourth case the company has purchased some new, highly mechanized equipment to be used on an experimental basis in an existing cabinet plant and later re-installed in a planned new plant. This new equipment includes, for example, two different high-speed widebelt sanding machines that together cost $40,000 and have about six times the production capacity of the machines they replaced. They meet present production requirements in one and one-half days per week, and will allow for a substantial increase in production when installed in the planned new factory. The new equipment also includes, for example, an experimental high-temperature oven that cost about $12,000 and, if successful, will allow the faster curing of new synthetic varnish finishes. Such experimental usage of equipment is not usual in the industry, and reflects a professional manager's quest for the best in equipment and procedures.

The company has also purchased some new equipment to be used in the smaller furniture plant and later re-installed in the planned new plant. This new equipment includes, for example, two new automatic shapers that cost about $35,000 and presently operate at 50% of capacity. A new conveyorized finishing line has also been installed at a cost of $200,000 and presently operates at about 65% of capacity. The most interesting feature of this new line is its integral environmental control system, which allows close control of the temperature, humidity, and cleanliness of the atmosphere. This in turn permits both deluxe and standard finishes to be applied on the same line at the same time. Spray-gun operators on the line have been given special training in spray-painting techniques by the equipment manufacturers.

(9) Resetting production standards. When new equipment is installed, it is generally necessary to re-evaluate production processes so that new quality standards can be specified. This was noted in all industries visited. It is also generally necessary to obtain new production time standards to be used as a basis for production scheduling and wage incentive schemes. Insofar as possible, such standards should

be pre-estimated, before the new equipment is purchased. This has often been done by visiting plants where similar equipment has been installed, and by making appropriate inquiries of the users of similar equipment, or through trade associations.

(10) Specification of equipment. Machinery manufacturers and vendors are perhaps best qualified to judge the merits of their own products and the suitability of their application to specific production operations. However, the manufacturers and vendors are generally not qualified to coordinate the design and installation of the variety of machines needed in an integrated, highly mechanized production system. This applies in particular to the introduction of a machine into a system where other components are of different origin. The manager of a small manufacturing company probably knows more about his own production system than anyone else. We have found managers to be most knowledgeable of pertinent technological advances, but less favourably situated for the planning and redesign of the system in order to accommodate them. Under these conditions, the manager has had to work out the selection of equipment, and specifications for modifications and installation, with the joint assistance of engineering consultants and equipment suppliers. The matching of automatic machines and materials handling equipment has required carefully detailed sets of specifications. In some instances, detailed specifications of follow-up service and maintenance by the vendor, and specifications of spare parts and supplies (lubricants, lapping compounds, etc.) have also been required.

(11) Inspection and quality control. Mechanization tends to reduce the number of work stations at which inspection can be carried out. In service industries, laundries and dry cleaning for example, in-process inspection becomes virtually impossible except at logical break points. On the other hand, mechanized production methods tend to give more uniform performance so that methods of statistical quality control can be applied with greater effectiveness.

An interesting comment on quality control comes out of one plant where thermostat calibration is carried out automatically by a feedback control mechanism. This device is found to give better and more consistent calibration than human operators were capable of giving, and has in fact allowed some relaxation of other manufacturing tolerances because of this improvement in final calibration.

Certainly, because of the speed of some mechanized processes, inspection operations presently carried out by people may have to be replaced by automatic machine inspection operations (e.g., automatic measurement of the dimensions of extruded, rolled, or coiled products, automatic weighing of packaged goods, automatic measurement of surface roughness, ultrasonic testing for cracks or flaws, etc.).

Economic Factors

Economic factors are among the most important to the small or medium-sized manufacturer, and the following should be considered early in feasibility studies.

(1) Book values. By itself, the book value or recorded accounting value of existing equipment may be quite irrelevant for management decision on equipment replacement. Book values are based on historical costs and arbitrary accounting conventions regarding depreciation, and fail to reflect either the current market value of equipment or its value to the firm as an economic factor of production. Book values of equipment are usually based on an arbitrary depreciation rule such as, for example, a straight-line depreciation over three years, or a three-year "payback period". In many of the cases studied, decisions to buy new equipment were based on an arbitrarily selected payback period of two or three years. The rather rigid adherance to this criterion seemed to be based on an unrealistic rate-of-return goal and on an inherited tradition, and it tended to inhibit longer-range planning to meet technological changes.

(2) Capital cost allowance. Sometimes book values of equipment are based on depreciation rates corresponding to the capital cost allowance specified by the Income Tax Division of the Department of National Revenue. These book values are a measure of the ability of equipment to generate depreciation charges which are legally deductible from income before taxes. (The standard allowance is 20% of an annually diminishing balance.) In some of the cases studied, the capital cost allowance was not considered to be an important factor in

equipment replacement decisions. However, in several cases equipment was financed on a short-term basis out of retained earnings or short-term loans, and the rate of the capital cost allowance was considered to be very important. Equipment replacements in two of the wood furniture companies, for example, were greatly facilitated last year because of the accelerated capital cost allowance (50%) extended in certain designated areas.

(3) Economic values. In decisions concerning equipment replacement, relevant economic costs should be used instead of irrelevant accounting costs. Two main cases arise. The first case involves the procurement of new equipment to manufacture a new product which is added to an existing product line. In this case the new equipment can be considered independently of existing equipment because it has no effect on the revenues and operating costs involved in the production of the existing product line. Under these circumstances the new equipment is justified if the discounted present value of all its future revenues exceeds the discounted present value of all its future costs. (The discounting procedure itself is mechanically straightforward and can be found in books on equipment investment, industrial engineering handbooks, and publications of the Machinery and Allied Products Institute, for example[1]. However, the choice of an appropriate interest rate is not so easy. The selected interest rate should be at least equal to the firm's cost of money.

The second case involves either the replacement of some existing equipment or the addition of new equipment. This case differs from the first one in

(1) "A Practical Manual on The Appraisal of Capital Expenditure", C. G. Edge, The Socity of Industrial and Cost Accountants of Canada, Hamilton, Ontario. See also the paper "The Economic Justification of New Equipment" prepared for this Conference by Mr. Edge.

that the new equipment is to be integrated with existing equipment in the production of various items of the product line, and cannot be analyzed independently. Under these circumstances the new equipment is economically justified if the discounted present value of its future incremental revenues exceeds the discounted present value of its future incremental costs. The term incremental revenue refers to the additional revenue that can be generated by the entire production system after the new equipment is operating. The term incremental cost refers to the additional cost or reduction in cost of operating the entire production system after the new equipment is operating. In this case notice that it is only necessary for the equipment investment decision to take into account the changes in total revenues and costs. Fixed costs that remain unaffected by the decision - e.g., "burden" charges connected with factory space allocation, some material costs, and so on - can be left out of the equipment investment analysis. Certain pricing and other decisions may of course be based on full costs, but the alternatives of existing and new equipment need only take into account differences in cost.

Analyses of the kind discussed above, based on relevant economic values, were not employed in any of the cases studied, chiefly because of the complexity of the analysis and the lack of professional staff to do the job.

(4) Financing. Two kinds of capital are involved in the financing of a company: equity capital and loan capital. Most of the small enterprises included in our study turned out to be family-owned, private incorporated

companies. As such they had a limited number of shareholders, some of whom were actively engaged in the operations of the enterprise. While public incorporated companies can sell shares to the general public to raise equity capital, private incorporated companies cannot do so. For this reason most of the companies studied were severely limited in their ability to raise new equity capital for equipment purchases.

Now let us consider debt capital, which falls into one of two main classes, either short-term loan capital or medium-to-long-term loan capital. Short-term loan capital is generally employed to maintain the current or "working" assets of a company at a safe operating level. It is used, for example, to meet payrolls and to finance short-term inventories. Medium and long-term loan capital is generally employed to finance the fixed assets of a company, assets such as buildings and production equipment. (Assets having a length of life greater than one year are generally considered to be fixed assets.)

In all of the cases studied, financing turned out to be one of the most important factors affecting equipment replacement decisions. The method of financing varied considerably from case to case, reflecting not only different financial conditions but also different management attitudes. For example, of the four wood furniture companies studied, one had financed equipment replacements piecemeal out of retained earnings and short-term bank loans and had severely impaired its working capital and bank credit rating. One had financed piecemeal on a two-year basis through industrial finance company loans. One was actively engaged in a major equipment replacement and expansion programme financed out of long-term secured loans by the Industrial Development Bank. And one, a division of a larger diversified company, was planning to finance an equipment replacement and expansion programme through a debenture issue.

General Management Factors

In the cases studied, the following were among the more important factors affecting equipment replacement and expansion decisions.

(1) Marketing. The scale of operation of an individual company, both in production and marketing, depends on the size of the market. The penalties of small scale appear not only in the inefficient utilization of modern high-capacity production machinery, but also in the purchasing of raw materials, bargaining for freight rates, developing adequate management staff, and so on. In some cases, intensive effort can increase the share of the market and so mitigate the difficulties usually associated with small scale, non-exclusive sales force, lack of regional showrooms, etc.

In most of the cases studied, changes in materials and products were forcing the introduction of new equipment. In turn, the introduction of new high-capacity equipment was forcing a search for larger markets. Several of the companies studied were investigating the possibility of mergers or of co-operative production and marketing schemes. One of the manufacturing companies, for example, had affiliated with another company producing a complementary product line, and the two had integrated their marketing activities. In general, the production-oriented companies were becoming increasingly aware of the effects of marketing constraints on production.

(2) Cost accounting. The effective planning of equipment replacements depends on the availability of

good cost information. In most of the smaller companies studied, cost accounting was either primitive or not existent as a formal procedure. One of the companies for example, recently hired a consultant to establish a cost accounting system, and the owner-manager admits that he now knows production costs accurately for the first time.

(3) Product Design. Product design is intimately related to production process design in two ways. The advent of new materials and machines may require the redesign of existing products. Conversely, the design of new products may require the introduction of new machines and processes. In either case, the product design must satisfy the market. In most of the cases studied, product design seemed to be given low priority or to be carried out on the basis of inadequate marketing studies. However, there was one outstanding case. One of the dynamic small wood furniture companies had departed from industry tradition by retaining two top international furniture designers on an exclusive basis, at a cost of $30,000 per year. The company now has a backlog of about one year's orders for a line of distinctive, high-priced furniture, and is safely proceeding with an extensive equipment replacement programme.

(4) Labour relations. The introduction of new equipment in some cases required the displacement, transfer, or laying off of workmen. It also required the establishment of new standards for wage incentive schemes, and the re-training of some workers for different jobs. It therefore affected the social-psychology of the factory. Under these conditions union-management and worker-management relations could

have become strained. However, it is noteworthy that increased mechanization was not causing such strained relations in most of the cases studied. In general, the newer mechanized processes required a different kind of skilled labour than the craft-oriented processes they replaced.

(5) Staffing. Small companies face most of the same general problems as larger companies. However, they are either unable to attract the same professional staff or they feel that the cost of such staff is too great to be justified. In the cases studied, about one-half of the owner-managers recognized that they must try to keep up-to-date through some kind of continuing formal educational programme - attending evening university extension courses, short summer courses, special seminars, technical meetings of professional, management, and trade associations, and so on. It was found that the more successful managers were not only taking advantage of such programmes themselves, but were also advising their key personnel to do likewise.

5. CONCLUSIONS

Mechanization is ordinarily undertaken in order that a company may improve its competitive position within its industry. At the same time, mechanization generally implies a greater productive capacity for the company using it, provided that all bottlenecks are reduced to reasonable proportions.

The implication of these two results of mechanization, at least within the framework of the companies visited, is clear.

The company which mechanizes has enough demand for the speed of the mechanized production: or it expects a marked growth of the market or it is willing to emphasize its duty as entrepreneur and create its own market expansion.

In the industries visited, mechanization was generally aimed at more efficient satisfaction of existing markets, usually under pressure from more progressive competitors. In two cases only was it part of the regular expenditure to attempt to expand sales volume by, e.g., employing exclusive designers for the product line.

The case of mechanization for expected market growth is straightforward. The duty of management as entrepreneur is perhaps less clear. This paper has put much emphasis on careful economic and managerial analysis of mechanization hardware. But an aspect which should not be neglected in the overall survival of an enterprise is that of investment in future markets.

Investment in future markets, which must of course be the subject of intense analysis, might be associated with merger, or co-operative production and marketing schemes. The idea that each member of a consortium of two or more firms can specialize in the production of component parts or of a few products of a complete product line is worthy of consideration. In this way, new machines which are presently utilized at only 20% or 30% of their capacity could be more fully loaded.

Directly linked with mechanization, because of increased productivity, is the necessity to enlarge either markets, or share of the market by effective promotion. Industry-wide promotional schemes may increase the size of a market sufficiently to allow economic mechanization of its members in some cases. Promotion to increase share of the market may be effective at the expense of less progressive competitors.

The situation generally seen in the firms surveyed is that of manufacturers mechanizing to grow slowly if at all. This is primarily due, in the privately owned business at least, to their method of financing. Generally the owner-manager's policy is to finance out of earnings, or by taking short-term loans. There are open to the majority, however, a number of sources of long-term financing. For instance, both Federal and Provincial agencies provide means for financial assistance typified by the Industrial Development Bank which is a source of long-term secured loans.

Of equipment seen, mechanization had not advanced byond the use of repetitive cycle automatic machines (level 3). More generally level 0 or I machines were found, with some single cycle automatic machines (level 2), with a fairly low degree of mechanization.

This low intensity of mechanization is not unexpected, because all of the companies seen faced frequent set-ups and short productive runs of a wide range of product types. It was particularly observed that relatively few conveyor systems or other automatic handling devices were being used.

Generally the type I introductions seen, that of individual components into existing machines, did not have a large pay off while those of type 2, complete machines, repaid their cost quite well. This observation may reflect the choice of companies observed, but it is perhaps more likely to reflect the lack of overall planning in the choice of the less expensive equipment modifications. If the detailed reaction of type I introductions on the whole system, physical plant, financial position, and management function, were as well understood in the planning for type I and type 2 introductions, the pay-offs might well be equivalent.

In almost all of the cases studied, the owner managers were aware of technological developments, at least in general. For more complete information on specific devices, the manufacturers' representatives may be consulted, though the matching of various manufacturer's machines is generally the responsibility of the buyer. Trade organizations provide valuable information sources, while for highly specialized techniques, consultant experts in the field concerned may be employed.

The application of the analysis in depth urged by this paper is possible only if adequate data is at hand with adequate staff to use it. Work study, cost accounting, familiarity with new machines, processes and materials are essential. If the management of a small enterprise is an avocation, the labour-intensive relatively non-automated plant is an ideal though perhaps short lived, medium. If the management of a prosperous company is desired, a capital-intensive organization, possessing new management skills is necessary. Such management skills may be obtained by hiring or through self-education in University or other extension programmes.

APPENDIX I - LEVELS AND DEGREES OF MECHANIZATION

(a) Levels of Mechanization

Let us make the rather elementary observation that production operations require two main input factors: energy (or work), and information. Either or both of these inputs can be provided by men or by machines acting as substitutes for men. For example, when a man uses a hand saw to cut a piece of wood he does two things. He supplies the energy (work) to move the saw and to make the cut. He also observes the position and path of the saw and makes the necessary mental calculations to guide the saw along a preselected path; he processes information. Our classification of the level of mechanization is based on the extent to which machines are used to take over the energy-production and information-processing (skill) of men.

For most practical purposes it is sufficient to define six levels of mechanization numbered 0, 1, 2, 3, 4, 5. The following classification of six levels is based on a scheme proposed by George H. Amber and Paul S. Amber, in which they call the levels "orders of automaticity".* The classification is qualitative, and is applicable not only to individual machines but to integrated groups of machines or processes.

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* George H. Amber and Paul S. Amber, ANATOMY OF AUTOMATION, (c) 1962. Prentice-Hall, Inc., Englewood Cliffs, N.J. This classification is used by permission of the publishers.

Level 0 - Hand Tools and Manual Machines

Tools and machines in this class have no self-operating capabilities. They may give a mechanical advantage, through levers, screws, pulleys, inclined planes, etc., but they do not replace a man's muscle power. They may incorporate guiding and measuring devices, but they do not replace any of a man's manual dexterity (or mental information processing). Level 0 tools and machines include, for example, hammers, knives, block-and-tackle, typewriters (non-electric-powered), handlooms, foot-powered presses, hand trucks, wheelbarrows, etc.

Level 1 - Powered Machines and Tools

Machines in this class replace most of an operator's muscle power. However, they replace none of a man's manual dexterity (or information processing) capabilities. They may be powered by windmill, waterwheel, steam engine, electric motor, gasoline or diesel engine, etc., but men must position both the work piece and the machine for effective action. Level 1 machines include electric hand drills, drill-presses, air hammers, spray guns, belt sanders, grinders, electric typewriters, etc.

Level 2 - Single Cycle Automatic Machines

Machines of this class replace all of a man's muscle power except for the relatively small amount needed for loading and controlling. They also replace part of an operator's manual dexterity (information processing) operations. A human operator is required to load, initiate action, adjust, and unload machines of this class. However, once the operator has initiated action the machine will feed and position tools and work pieces automatically. Level 2 machines include, for example, pipe threading machines, precision boring machines, machine tools such as drills, grinders, mills, shapers, lathes, presses, etc.

Level 3 - Repetitive Cycle Automatic Machines

Machines of this type replace all of a man's muscle power except for a small amount needed for control (adjustment) operations. They also replace most of an operator's manual dexterity (information processing) operations. They obey internal (fixed) or external (variable) programmed instructions stored in the form of cams, tapes, or cards. However, they are not self-adjusting or self-correcting (e.g., for tool wear). They require a human operator to make certain measurements, to process certain information, and to make certain corrective adjustments or control operations from time to time. Level 3 machines include, for example, self-feed press lines, automatic copying lathes, automatic gear hobbers, automatic assembly of relays, valves, etc.; Detroit-style engine production lines; machines to make bottles, cans, bakery products, etc.; machines for automatic canning, bottling, packaging; automatic transfer machines; and numerically controlled lathes, milling machines, etc., that are not self-correcting.

Level 4 - Feedback Controlled Machines

Machines of this class can do the automatic operations of level 3 machines, but they are also self-correcting. They measure and compare results with pre-set standards and automatically make adjustments. This process of self-measurement and self-adjustment is generally called closed loop feedback control. For example, a machine may automatically measure the size of the part produced or the dimensions of a cutting tool and automatically adjust the tool position to account for wear. Level 4 machines include, for example, automatic size-controlled grinders, honing machines, etc.; dynamic balancing machines; weight or volume-controlled mixers and blenders; chemical milling machines; weight, volume, level, or flow-controlled chemical processes, etc. All of these are based on the automatic measurement and feedback of information about product attributes. Level 4 machines also include, for example, pattern tracing flame cutters, servo-assisted machine tool tables, spindles, and self-adjusting tape controlled machines. All of these are based on the automatic measurement and feedback of information about tool, pattern, and work piece positions, speeds, and orientations.

Level 5 - Computer Controlled Machines and Processes

Machines of this class replace the logical decision-making processes of a group of highly skilled human operators. The simplest self-correcting machines of level 4 measure and correct for one factor, or perhaps for several factors independently. But machines of level 5 can analyze and evaluate many process factors simultaneously, can solve complex process equations, and can make logical decisions according to rules pre-programmed and stored in a control computer's memory. Level 5 machines are most frequently used in continuous processes, and may employ either large general-purpose computers or small special-purpose computers. Level 5 machines include, for example, some paper-making machines, some steel rolling mills, some chemical processing plants and petroleum refineries, some power plants, and some selective assembly machines (e.g., for matching bearings and races).

(b) Degrees of Mechanization

In the preceding section we defined the levels of mechanization, and the qualitative classification was based on the extent to which machines replace the energy-producing and information-processing attributes of men. In this section we consider the degrees of mechanization, in which the classification is based on the ratio of automatic operations to total operations in a production process.*

If the direct production operations of a process are detailed according to standard conventions, the total number of operations can be divided into two main classes: automatic and non-automatic. For example, suppose an automatic screw machine is set up to make special fittings and that the machine recylces automatically once it is loaded and started (level 3). The machine's nine direct operations are load, chuck, turn, drill, ream, chamfer, pipe thread, machine thread, and cut-off. The first operation is manual, but the last eight are automatic. Then the ratio of automatic to total operations, or the degree of mechanization, is 8/9. Designating the level of this machine by L and the degree by D, we can describe the machine by the short notation L3,D8/9.

An automatic materials handling device (a conveyor or a shuttle) that simply moves work pieces from one machine to another is usually a level 3 machine having only one automatic operation, and is designated as

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* This definition is adopted from Amber and Amber, op cit.

an L3,D1/1 machine. A conveyor which moves, reverses, and inverts work pieces may be designated as an L3,D3/3 machine.

When a number of standard automatic production machines are linked together by standardized materials handling devices, the result is generally called an automatic line. For example, an L3,D8/9 and an L4,D9/10 machine linked by an L3,D2/2 conveyor can be designated as a single production unit, or line, as follows:

(L3,D8/9) + (L3,D2/2) + (L4,D9/10)

In this example, the only manual operations are loading the first production machine and inspection of the output of the second production machine.

Many modern L3 production machines (multiple cycle automatics) are designed in such a way that they can be loaded automatically from standard materials handling devices, and they can be unloaded automatically onto standard materials handling devices.

APPENDIX II - GLOSSARY OF PRODUCTION TERMS

Operation: - A distinct action such as load, feed, grind, unload, gage, etc. Operations can be grouped into six main classes: materials handling, working, inspecting, assembling, testing, and packaging.

Process: - A series of operations needed to produce a product.

Work: - The expenditure of energy to perform an operation.

Job: - A set of operations carried out by a man. (The term is also usually applied to a set of operations carried out by a machine.)

Tool: - The most primitive device used to carry out an operation; the device by which a piece of material or a product is held, shaped, cut, or formed.

Machine: - An assembly of related motors, tools, controls, and auxiliary devices that can be identified as a unit because its parts are mounted on a single frame.

Station: - The working place of either a man or a machine on the production line.

Transfer Machine: - A collection of machines linked together by automatic materials handling devices in such a way that it operates as an integral automatic machine.

Production System: - The set of all the factors of production needed to make, store, and distribute products, including men, materials, machines, processes, channels of communication, management controls, operating rules and regulations, tax and depreciation rules, union contract rules, customer's requirements and specifications, and in general the entire organizational structure and every internal and external factor that has a bearing on production decisions and the implementation of decisions.

APPENDIX III - COMPANIES OBSERVED

Wooden Furniture

Four companies in Ontario manufacturing wooden furniture were observed. Sales volumes ranged from $900,000 to $2.5 million, and employees on hourly payrolls varied from 97 to 350. Three companies were family owned.

Light Electrical

This was defined for purposes of the field study to exclude electronics and associated areas. The products ranged through small electric motors, electro-mechanical control devices, fan-heaters, heating controls, measurement equipment and small appliances. A number of sections of larger companies were observed, and though the capitalization is different from the small organizations visited, the level of mechanization is not judged to be greatly different.

Laundry and Rug Cleaning

A laundry in a small city specializing in shirt laundering was studied, as were two rug cleaning plants which also handled drapery, and a linen service company.

OTHER PAPERS PREPARED FOR THE CONFERENCE

"PRODUCTIVITY THROUGH NEW TECHNOLOGY"

TORONTO, MAY 27-28, 1965

The following papers prepared for the Conference are also being published by the Economic Council of Canada. They are available from the Queen's Printer, Ottawa. A brief description of the papers begins overleaf.

The views expressed in the papers are those of the authors themselves.

MODERN MANAGEMENT, by Gerald W. Fisch; Price 50¢; Catalogue No. EC 22-4/1

PRACTICAL APPLICATION OF DATA PROCESSING IN MEDIUM-SIZED AND SMALLER MANUFACTURING COMPANIES, by H. S. Gellman and R. C. Carroll; Price 75¢; Catalogue No. EC 22-4/2

ADVANCES IN METAL WORKING, by J. Vande Vegte; Price 75¢; Catalogue No. EC 22-4/4

IMPROVING MATERIAL MOVEMENT THROUGH THE MANUFACTURING CYCLE, by J. A. Brown and B. D. Beamish; Price 50¢; Catalogue No. EC 22-4/5

THE ECONOMIC JUSTIFICATION OF NEW EQUIPMENT, by C. G. Edge; Price 75¢; Catalogue No. EC 22-4/6

The following two addresses delivered at the Conference are available without charge from the Economic Council of Canada, Post Office Box 527, Ottawa.

OUR CHANGING ECONOMY, by John J. Deutsch
Chairman, Economic Council of Canada

TECHNOLOGY AND PEOPLE, by William Dodge
Executive Vice-President
Canadian Labour Congress

MODERN MANAGEMENT, by Gerald G. Fisch

Mr. Fisch is Managing Partner of P. S. Ross and Partners, Management Consultants, and a Principal of Touche, Ross, Bailey and Smart, Chartered Accountants.

This paper is a concise account of the widespread successful application of some of the new techniques, new approaches and new concepts of business management now being used in or available to businesses in Canada. The author points out that these new techniques involve greater precision in management. He argues that this precision -- and an end to the old "seat of the pants" approach to management -- is demanded by the accelerating tempo of change, the demands of a growing ambitious population, and the pressures of rapidly developing technology.

PRACTICAL APPLICATION OF DATA PROCESSING IN MEDIUM-SIZED AND SMALLER MANUFACTURING COMPANIES, by Dr. H. S. Gellman and R. C. Carroll

Dr. Gellman is Vice-President, Research and Analysis, and Mr. Carroll is Chief Analyst, of DCF Systems Limited, Malton, Ontario.

At the beginning of 1965 there were more than 24,000 computers at work in the United States and approximately 650 in Canada. This paper is designed to show the managers of small- or medium-sized manufacturing companies what can be done with some of the modern equipment for automatic data processing, towards improving the operation and control of the business. The paper includes the results of a questionnaire survey of several hundred Ontario companies on their use of data processing. Thirteen case studies show the actual cost, application and benefits of ADP in the individual companies.

ADVANCES IN METAL WORKING, by Dr. John Vande Vegte

Dr. Vande Vegte is Assistant Professor of Mechanical Engineering at the University of Toronto, and a Principal in the consulting firm of Systems Engineering Associates Limited, Toronto.

His paper is designed to acquaint owners and managers in the metalworking industry with a wide range of new developments in manufacturing technology. Discussed at length is one of the most important of these new developments, numerical control of machine tools. There are about 5,000 of these machine tools in operation in the United States, and the U.S. Labor Department estimates that 12,000 may be in operation by 1967. Canada at the start of 1965 had 46 "NC" machines in operation. This paper also reviews developments in cutting and forming, and discusses improvements in the productivity of machine tools by the addition of modern attachments and accessories.

IMPROVING MATERIAL MOVEMENT THROUGH THE MANUFACTURING CYCLE, by James A. Brown and B. D. Beamish

Mr. Brown is a Partner in Woods, Gordon and Company, Toronto. Mr. Beamish is an automation consultant in Toronto.

This paper is broad in scope, describing how firms might reduce or eliminate material handling and minimize the movement of material through the manufacturing process and to the customer. It pays particular attention to the new developments in the shipment of raw materials and finished goods, warehousing, in-plant handling, and handling at the workplace. One of the authors' findings from a survey of manufacturing companies in Ontario was that few if any of the firms had usable data on their material-handling costs.

THE ECONOMIC JUSTIFICATION OF NEW EQUIPMENT, by C. G. Edge

Mr. Edge is Director of Management Services for Chemcell (1963) Limited, and Assistant to the President, Columbia Cellulose Limited.

This is a paper on how to appraise capital expenditures through the use of sound methods of relating the future benefits to the outlay, estimating future benefits, and administering and controlling projects. Various methods of determining the economic justification of capital expenditures are discussed but emphasis is given to the use of the Discounted Cash Flow method. Three ways of using the DCF general method are described -- internal rate of return, present value, and equivalent annual costs. Adequate examples plus tables and charts provide sufficient information for the understanding of the significance of each of these methods.

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