PROJECT SUMMARY

The objective of this work is to provide process industry practitioners with tools for finite capacity production planning and scheduling. These tools will possess the following characteristics: accessible to practitioners; account for appropriate costs; can be implemented on personal computers; account for varying demand; account for capacity limits.

Production planning/scheduling methodologies developed must cover as broad a spectrum of process industry environments as possible within the constraints of the project scope. To accomplish this, environments will be defined and ranked: using the process industry experience of the principal investigators; the Process Industry Special Interest Group Steering Committee of the American Production and Inventory Control Society (APICS); industry members of the Center for Process Manufacturing at Penn State-Erie; the APICS Annual National Meeting; practitioner workshops on tools developed by this project; surveys of System Integrators.

Production planning and scheduling models which emerge from this process will be examined for optimal solutions using dedicated software or cut-generation and variable redefinition techniques. For those models which do not yield to exact procedures, heuristics will be developed and tested. Tests will include computation time, an appropriate gap measure and robustness to changes in problem parameters.

The process industry is characterized by shallow bills of material, multi-product manufacturing and accounts for approximately 40% of U.S. manufacturing enterprises. It has not been well served by existing MRP systems, which typically assume infinite capacity, do not properly account for costs in lot sizing, and are best suited to multi-level, single product manufacturing environments.

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Appendix Items:

*Proposers may select any numbering mechanism for the proposal.

PROJECT DESCRIPTION

Objective

The objective of this work is to provide process industry practitioners with tools for finite capacity production planning and scheduling. These tools will possess the following characteristics:

- Accessible to practitioners
- Account for appropriate costs
- Can be implemented on a personal computer
- Account for dynamic demand
- Account for capacity limits

In order to achieve this goal, five major activities will be carried out:

1. Development of management science models for production planning and scheduling appropriate to the process industry environment.
2. Testing of models for optimal solutions and development and testing of heuristics when necessary.
3. Translation of solution methods into clear, step-by-step procedures that can be implemented on desk-top computers.
4. Dissemination of proven tools through practitioner journals, seminars, workshops and newsletters.
5. Continuing maintenance of a library of related studies from journals and texts.

Detailed descriptions of these activities will be provided under the General Plan of Work below.

Significance

The process industry accounts for some 40% of U.S. manufacturing enterprises. As de Matta and Guignard (1994) state: "Process industries generally produce products to stock. Products compete more on price, and thus, operating at a low cost is a top priority for these industries to stay competitive. This requires careful planning and close monitoring of production activities." Generally, process industries use few raw materials to produce many end items. The manufacturing process is predominantly single level often with non-negligible set-up times and costs, particularly between family groups. Dynamic demand (sometimes promotion driven) and escalating customer service expectations often require substantial finished goods buffer inventories. As a consequence, the industry is not well served by existing MRP systems which are primarily targeted toward multilevel manufacturers. Furthermore, most MRP lot sizing systems assume infinite capacity and do not account for holding and set-up costs (lot-for-lot) or make inappropriate use of the EOQ lot sizing model.

Many current scheduling software packages claim finite capacity capability but this is typically accomplished by the user in an interactive trial-and-error process, independent of cost considerations. The black-box, one-size-fits-all nature of these packages can make adaptation to existing systems time consuming and expensive.

In short, process industry manufacturers face the unpleasant situation of buying an MRP system which does little more than help in the timing of purchase orders and adding, at great cost, a scheduling system which provides only cut-and-try feasibility. The answer to this dilemma lies in providing practical, optimum (or near optimum) planning and scheduling tools directly to the manufacturers in understandable format.

But this is easier said than done. The problem of capacitated lot sizing with set-up times is known to be NP complete (see Trigeiro, et al (1989)). Most of the relevant research appears in academic journals in a form suitable only for academic specialists. A mechanism is needed to translate these sophisticated mathematical tools into practical terms. Such a mechanism was recently established at Penn State-Erie: the Center for Process Manufacturing, jointly sponsored by Penn State and the American Production and Inventory Control Society (APICS). This is the first such joint venture between APICS and a university and the general objective of this Center is to improve the productivity of the process industry by fostering implementation of management science methods. The work of this proposal fits directly within the purview of the Center for Process Manufacturing.

Relation to Professional Development of the Investigators

All of the principal investigators are members of the Center for Process Manufacturing at Penn State-Erie. Two of the P.I.s have spent the last two years designing and implementing a finite capacity production scheduling system for **Welch's**, a major food manufacturer (see Allen and Schuster (1994)). The results of this work were presented in June of 1994, at a one and one-half day technical conference for practitioners by the Center for Process Manufacturing and co-sponsored by Penn State-Erie, APICS and the Ben Franklin Institute of Pennsylvania. Conference participants solved mixed integer linear programs for aggregate scheduling and disaggregation in an Excel spreadsheet environment using a **What's Best!** overlay. The capacitated aggregate model included set-up costs and time and was based on actual demand and cost data from a **Welch's** production line.

All of the P.I.s have ongoing relationships with process industry firms through full time employment or on a consulting basis. All have strong interests and experience in the major tools essential to successful production planning and scheduling: linear, non-linear and mixed integer programming and development of heuristics.

Relation to Present State of Knowledge

A very large body of literature exists on production planning and scheduling. Most of this has appeared in academic journals, seldom read by practitioners, and is very demanding technically. The investigators will rely heavily on this current work both for guidance in model building and for solutions methodologies. It will of course be necessary to develop new models or model variations to meet specific circumstances.

However, the primary challenge lies in the validation and testing of these models under a variety of conditions and in transforming the language of mathematics into a form transparent to the practitioner.

For single level capacitated lot sizing (CLSP) with set-up times, we have the work of Trigeriro, et al (1989) as a foundation. This work is easily modified to incorporate buffer inventory requirements common to the process industry. The case of multilevel lot sizing (with a bottleneck operation) accounting for set-up time has been examined by Billington, et al (1986). While multilevel processing is not common in the process industry, Billington's work provides a basis for development of practical lot-sizing methods for those instances.

Salomon's (1991) monograph provides an extensive bibliography on a wide range of lot sizing problems and treats in depth the discrete lot sizing and scheduling problem (DLSP) capacitated and incapacitated, single and multilevel, with and without set-up time. He points out in this work that practical implementation of these models deserves to be the subject of a separate research project. We cannot but agree.

Axsäter and Nuttle (1987) have provided a method for collapsing complex multi-level assembly structures into simpler structures. We are unaware of any practical applications of this procedure but it appears to hold promise for the work proposed.

Frequently, in the process industries, production lines are dedicated to a specific group of products. Whenever end items can be grouped into families having similar set-up times and costs and production rates, a hierarchical approach to production planning is appropriate. This has the desirable consequence of reducing binary set-up variables and breaking one large problem into a set of subproblems of smaller scope. Hax and Candea (1984) have summarized much of the important work on hierarchical systems and a more recent bibliography by Bukh (1993) brings this work up to date. DeMatta and Guiguard (1994) have examined the problem of assigning product families to flexible production lines and determining family production quantities by period to minimize production, holding and set-up costs. However, set-up times are not accounted for.

When set-up times are negligible and the set of products is fixed for a single-level production line, Maes and Wassenhove (1988) have provided a general review of special purpose heuristics and mathematical programming based heuristics.

It is important to realize that the methods discussed so for are more properly regarded as production planning tools since they typically deal with long time horizons and "large" time buckets (weeks and months). None of these methods treat sequencing of multiple items within a time period. The problem of end item frequency and sequencing has been examined extensively over many years. Some of the more notable efforts are those of Delporte and Thomas (1977) and Dobson (1987). These models are applicable to a constant demand situation and determine cycle length as one of the variables. Furthermore, the cycle is assumed to be repeated indefinitely into the future. But the planning models appropriate to most process manufactures yield a set of end items to be produced within a fixed time period. In addition, each period may require production of a different set of end items. It is unclear how much additional cost savings are attainable with optimal sequencing of end items within each time period. The higher level planning model has presumably already minimized major cost components while meeting demand under capacity restrictions and has provided a feasible plan. Precedence restrictions on set-ups for certain end items may further constrain the problem. Aras and Swanson (1982) have solved a finite horizon, dynamic demand problem for lot sizes and sequencing. However, no set-up costs are incurred and the first and last items must be specified. Perhaps simple n job, single machine heuristics should serve as well.

<u>Relation to Work in Progress by the Investigators</u>

Edmund W. Schuster's research interests address practical application of operations research to solve problems facing the process industries. His areas of concern include finite capacity planning, production scheduling and plant/warehouse location analysis. He has a particular interest in hierarchical planning systems to solve finite capacity problems. Most of his research is used to deal with actual production and inventory management problems encountered as part of his responsibilities at **Welch's**. The applied nature of the proposed work fits with his desire to expand the use of management science tools among practitioners in the process industry. This desire is attested to by his past and continuing involvement with the Process Industry Special Interest Group of APICS and his leadership in founding the Center for Process Manufacturing at Penn State-Erie.

Stuart J. Allen recently spent 15 months (May, 1992 to August, 1993) in full-time residence at **Welch's**, a major U.S. food producer. During that time, he worked with Edmund W. Schuster on a number of problems specific to the process industry: finite production planning and scheduling, optimum plant and warehouse location analysis, raw materials logistics planning, new plant siting analysis, optimal scheduling, strategic planning for plant/warehouse capacities. All of these areas are still the subject of on-going research efforts and all are directly related to the proposed research effort.

Michael P. D'Itri's relevant research interests focus on sequence dependent production scheduling where the produced stock is cut into finished products. Although this work has centered on the paper industry, the models and solution procedures he has developed have applicability across a wide range of process related industries, including steel, textiles and glass where a variety of products are produced and the decision makers use a rolling planning horizon.

Jack Martin's research focus is on the use of computer science and operations research techniques for management decisions. Specific areas include optimizing exchange agreements in the refining industry and capacity planning in the process industry.

General Plan of Work

In order to achieve the objective of providing effective and useful production planning tools for the process industry, five major activities will be carried out: development of appropriate models; model testing and evaluation; translation of procedures into practitioner language; dissemination of proven tools; maintenance of library of related studies. These will be enlarged upon below.

1. **Development of production planning and scheduling methods appropriate to the process industries.**

Two competing goals must be dealt with: covering a broad spectrum of process industry planning/scheduling environments versus consistency of the effort with time and number of personnel involved. In addressing this dichotomy, we will concentrate efforts on the following classification of problems:

- Dynamic, deterministic demand
- Make to inventory
- No backordering allowed
- Finite production capacity
- Non-negligible set-up times

- Multi-item, single level process
- Multi-item, multi-level processes
- Finite, discretized planning horizon
- Deterministic lead times
- Sequence independent set-up costs and times

Other issues, which will have to be resolved as part of the model building process, involve: multi-period per item batches ("small" time buckets); multi-items per period ("large" time buckets); "all or nothing" production rate models and variable or parametric production rates.

The classification scheme for focussing the proposed work should be viewed as providing flexible guidelines and not as a rigid framework. If the results are to be acceptable to practitioners, the models must address planning/scheduling problems faced by the industry. The major effort in this phase of the work must be devoted to formulating real problems. In order to formulate real problems, we propose to obtain direct practitioner input into the modelling process using several mechanisms:

- Edmund W. Schuster, one of the principal investigators, is Manager of Logistics Planning at **Welch's**, a major food producer. He is also Associate Director of the Center for Process Manufacturing at Penn State-Erie.
- Two of the Principal Investigators are on the Process Industry Special Interest Group Steering Committee. This committee or a special action subcommittee will be used to provide guidance on model characteristics suitable to process industry concerns while reaching a wide segment of that industry.
- Industry members of the Center for Process Manufacturing will similarly be called upon for guidance on models and potential for applicability.

- The Annual National Meeting of APICS provides dedicated time for each of the Special Interest Groups. The process industry allocation will be used to state the goals of the Center's planning/scheduling research efforts and to solicit constructive suggestions on model construction in a structured fashion, e.g. panel discussions and surveys.
- Products resulting from the work on this proposal will be presented twice yearly to practitioners in hands-on workshops. Time will be set aside for a critique by participants and suggestions for new directions.
- Systems Integrators have been a source of unbiased information and are interested in current developments in practical production planning/scheduling tools. We expect to call on select members of this group to explain our activities and discuss needs and directions.

In summary, the model building process will be dynamic, continuing throughout the term of the proposed work and providing a foundation for future activities.

2. Model testing and evaluation.

The set of planning/scheduling models screened in step 1, described above, will be tested in a three stage process. We expect that most candidates will require, at their core, solution of mixed integer linear or non-linear programming problems. Some few of these may yield to optimal solutions using standard software (LINDO, GAMS/MINOS).

At the second stage an investigation of other "exact" solution procedures is in order (see for example Barany et al (1984), Leung et al (1989), Eppen and Martin (1987)). These are based on cut-generation and variable redefinition techniques used in conjunction with branch-and-bound.

In the final stage, heuristics will be investigated. The model for this stage is provided by the work of Maes and Van Wassenhove (1988). In their review of multi-item, single-level capacitated lot-sizing heuristics, they classified the different approaches into special purpose heuristics and math-programming-based heuristics. Another of their goals was to determine the relationship between the performance of various heuristics and the computational burden.

Another aspect of candidate heuristics must also be considered: general robustness to changes in problem parameters. Trigeiro et al (1989) considered several such factors for a specific heuristic for capacitated lot sizing with set-up times. Some of the factors which may significantly affect computational burden or performance: problem size; tightness of capacity constraint; variability of demand, set-up time and cost across items; existence or tightness of inventory capacities; existence of buffer stock requirements.

Where proven heuristics exist, for a given model they will be retested; when competing heuristics are available, they will be tested for robustness; when none exists, heuristics will be developed and tested using an appropriate gap as performance measure and a reasonable range of problem parameters to examine robustness.

3. **Translation of formulation and solution procedures.**

The goal of this activity is to provide a complete package to practitioners summarizing all important aspects of each planning/scheduling method developed in parts 1 and 2, described above. This will consist of:

- A complete listing of all model assumptions and areas of applicability.
- A complete statement of the model structure in both English and expanded symbolic form.
- A complete description of the steps required to obtain a solution and associated software requirements.

- Suggested stopping rules for heuristic solution procedures.
- Recommended limits on model parameters, e.g. problem size, number of end items, demand variability and other factors found in part 2.
- An example application, drawn from actual data whenever possible, and including

  Model summary

  Solution summary

  Software and hardware used
- Provision of a "helpline" phone number for those practitioners who encounter difficulties in duplicating the example application.

4. Dissemination of the tools developed.

Several means will be employed to bring the planning/scheduling tools to the practitioner.

- Practitioner workshops

  Two workshops will be offered annually, patterned after the successful planning /scheduling workshop given at Penn State-Erie in June of 1994. APICS will again underwrite advertising and brochure mailings and we expect the Ben Franklin Institute will again join in sponsorship for any workshops held in the state of Pennsylvania.

  The workshops will present the results of tool development as described under part 3 above and will incorporate a computer lab for model solving. In addition, time will be set aside for critique of the models and for suggestion by practitioners on future developments.
- APICS National Conference Presentations
- TIMS/ORSA Joint National Conference Presentations

- APICS Performance Advantage and PISIG Newsletters

  These forums are ideal for non-technical descriptions of research results suitable for practitioners and have wide circulation.

- Publication of results in practitioner and academic journals.

5. **Maintenance of a library of related studies.**

We presently possess a considerable body of work related to the proposed area of study and this appears in the Bibliography. Both P.I.s and graduate assistants will be responsible for adding to this library on a continuing basis

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