
Responding to Customer Enquiries in Make-to-Order Companies: Problems and Solutions

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ABSTRACT

Make-to-Order companies are in the business of supplying products in response to a customer order in competition with other companies on the basis of price, technical expertise, delivery time and reliability in meeting due dates. Dealing properly with enquiries is the major problem that MTO companies face. A lack of co-ordination between sales and production at the customer enquiry stage often leads to confirmed orders being delivered later than promised and/or being produced at a loss. The treatment of an enquiry is a multi-stage decision process. The initial decision is whether or not to prepare a bid, and if so, how much effort to put into the specification and estimation process. The MTO company has the choice of putting in a lot of effort to prepare a competitive bid or making a quick estimate with a high safety margin to allow for errors and unforeseen problems expecting further later negotiation with the customer. Consideration has to be given to the likely accuracy of the cost estimates produced. The feasibility of being able to produce the order with the current work load at different delivery times needs to be evaluated together with any extra costs incurred. An Input/Output planning approach based on the control of a hierarchy of backlogs of work is proposed to produce a dynamic capacity planning model to determine the capacity to provide at each work centre in future time periods, allocating overtime, transferring operators, process as split batches etc. In setting the price and lead time to quote to the customer, the probability of winning the order plays an important role. A model based on a Chi-squared analysis of data on past enquiries is proposed to divide the market into sectors of similar orders. It is extended to produce a Strike Rate Matrix for each sector giving the probability of winning orders in that sector as a function of the price and lead time quoted. A general model for the whole enquiry process is presented together with a Decision Support/Expert System. This indicates where the qualitative judgmental rules, typically used by companies could be used to advantage.

1 -The Problems of Make-to-Order Companies

In general, manufacturing companies are divided into two types - Make-to-stock (MTS) and Make-to-order (MTO). The basic distinction between the two types is the timing of the receipt of the customer order. In the MTS sector, all of the production is complete when the order arrives and the customer requirements are supplied from stock. In the MTO sector, some or all of the production takes place after the customer order has been received. Thus in the latter sector, there is more flexibility in customising the products to meet the specific needs of individual customers.

MTO manufacturing covers a range of activities. In the pure engineer-to-order company (ETO), the order is received before the design stage. The customer typically only describes the functions and characteristics it wishes the product to have. The ETO firm has to produce a design and specification of the product to meet these requirements. The order may be for just the design stage or for both design and manufacture. These companies usually make one-off products. A survey by Tobin, Mercer and Kingsman (1988) found many such companies within the capital equipment industry, mostly manufacturers of machines for making things.

At the other extreme is the sub-component manufacture-to-order company, the classic job shop, where the

customer supplies the design and it is only necessary to configure how to make it with the machines and skills in the company. Each order may be very different to any other. There may be some repeat production and the provision of spares. In other cases the company may offer a range of specialist products. However, the orders arrive for only small quantities and at intermittent time intervals. So, every thing that is made by this type of company is only made after the order has been received and the products supplied may also contain some customised components. In some cases, these companies are selling a skill to perform certain types of operations rather than an actual product.

This research is aimed at the MTO sector of industry covering both the manufacture-to-order subcontracting firms and the engineer-to-order capital goods manufacturers. The two most important characteristic of these firms are:

i) Each order typically requires different amounts of processing work on the work centres of the firm, the use of a different number and/or different sequence of work centres. In one small sub-contracting company, which processed 104 orders in one 12 month period there were 100 different routings required through the 14 work centres. The orders are for a small number of units of the product, often being only one in capital goods manufacturing. Batch production, with some inevitable work—in-process stocks between work centres, is the production system to be used. It is very

difficult to make forecasts of the loads on facilities a long way ahead.

ii) The firms are involved in competitive bidding for orders. When a customer makes an enquiry for a product, they will usually ring several other suppliers at the same time and will then compare quotes before choosing the company with which to place their order. Tobin, Mercer and Kingsman (1988) found that the strike rate, the proportion of quotes that become firm orders, varied from 3% to virtually 100%.

The bid these companies make in response to a customer enquiry must contain realistic and currently competitive Delivery Dates (DD) and prices. These are the crucial factors in winning the order, although other aspects such as the company reputation for technical skill and quality, the financing package etc., may be important also. Promising a 2 week delivery but consistently taking 10 weeks will soon become known and lead to customers going elsewhere. Always quoting ridiculously low prices will lead to bankruptcy. It is necessary to choose the DD and price to quote bearing in mind both the associated production planning problems and the associated probability of winning the order. Thus both production and marketing aims and objectives should be taken into account.

Each sector of industry experiences different decision making problems in relation to the type of customers they serve, their customer needs and the type

of competitive environment in which they operate. Thus different production and marketing control systems are required for each sector. In this research the MTO sector is addressed - the needs of these companies has often been neglected in the past in favour of the MTS sector. In particular, how an MTO company deals with and responds to customer enquiries is its most important activity, since this determines how much business it will have and its profitable survival.

2. How Enquiries are Dealt With

Although customer enquiries can arise in a variety of ways, dealing with enquiries is a four stage process as illustrated in Figure 1. In capital goods suppliers, this may be formally organised, with all stages explicitly covered by committees set up for the purpose. In small component suppliers and engineering services companies, it may be much more informal with the stages being combined together and carried out by one man.

The first stage is an initial evaluation to determine whether the company wishes to make a bid for the job. The issues here are questions of being able to and wishing to do the work requested. Clearly if it is a product that has been produced before or similar to such a product, the decision is obvious. If it is a new product, then the company needs to check if it has the skills and facilities to make it, or can hire them or can subcontract out parts of the work

involved. In some cases the customer may ask for a particular delivery date and/or a price limit, so this must be considered as well as the ability to be able to do the work requested. If the company is currently heavily loaded, and the customer has indicated it wants a quick delivery, it may decide not to bid. A very crude check is usually made on the likely profitability of making the order. Strategic issues are also often considered, such as the wish to move into a new market, so willing to work at a loss on this order for an opportunity to develop new skills, or the need to keep a valued customer happy, even though the product requested is outside the usual type of order placed. The outcomes of this stage are:

- a) Decide to prepare a bid
- b) Refuse to bid
- c) Seek further clarification on the request.

The second stage is to define how the cost estimates will be made. This means specifying how much time should be spent in the estimation process, for example, preparing a very detailed specification and costing all components of the work as accurately as possible, or concentrating only on crucial parts of the work and using average effort and costs for the rest of the work. In most cases, the company has to respond to the customer enquiry within a limited time. The general view expressed by companies is, that this limited time plus the costs of estimating and having to bid for many more jobs than are won, means that you can rarely carry out a completely

detailed specification and then accurately estimate all components for all jobs. It is necessary to decide how to spread the available estimation effort, not only within a particular enquiry but also between the different enquiries being considered at any one time. Theoretically, the cost estimation stage should be independent of the price setting stage. However, because of the practical constraints and realities, as just outlined, this is not possible. Thus the likelihood of getting the job, the current competitiveness, the company relationship with the customer, the size and importance of the customer, whether there will be an opportunity to revise the job specification etc., all play a role in the decision making at this stage.

The third stage is the process of preparing the cost estimates themselves. This includes the specification and configuration of exactly how the job will be made, what materials to use and what processes will be required in what sequence and amounts. The enquiry could require mechanical and electrical design, machining, fabrication and assembly work, production of software and installation in the customer's factory. Different specialists will be required for each area, including both designers and estimators. The general approach taken in MTO companies is to base the costs on the estimated number of hours of direct work activity required and the materials needed. Direct activities are those measured during production, e.g. spent on drilling, milling and boring machines, in fabrication and assembly work. Usually standard hourly

costs per work activity are calculated and set once per year. Indirect activities, all the other costs of running the business, including design and estimation, are covered by multiplying the direct costs by some factor, which may differ between labour/ machine costs and material costs.

When pressed, companies mention that the work load and production plan should be checked to determine if and when the job can be carried out and delivered. However, in general this appears not to be done, or, if so, only in a superficial manner.

The final stage is the setting of the price and lead time to bid. Here the question is usually to determine what profit margin to add to the cost estimate. This depends upon a range of factors; for example, the belief of the chances of winning the job, the amount of competition for this job at this time, the customer and the company's relationship with the customer, the company's need for work etc., as discussed earlier. It is also dependent upon how the cost estimates were prepared. If the configuration and cost estimation process were given reasonable time and done with care, then the profit margin could be narrowed to increase the chance of winning the order. However, if it were a quicker and cruder estimation, then the price is likely to be set higher to compensate for adverse variances in the actual costs. For significantly sized jobs, this stage is usually carried by a committee of interested parties from all parts of the company management, sales, estimation, production, technical etc, going by such

titles as the tender vetting committee, or the bid/no bid committee. This meeting may determine what price and lead time to quote to the customer, or decide to seek further information on the customer or current market conditions, or ask for parts of the estimation process to be re-examined in more detail. A further meeting will then come to a final decision.

The proposal is then put to the customer, who may accept it, reject it or ask for further negotiations. The further negotiations may just be asking for a lower price or could be a joint exploration of ways to change the job specification to try to reduce the cost. Another option met in some circumstances is for the customer to ask for a new price for a specific delivery date, different to the one proposed by the MTO company.

3. Problems and Neglected Opportunities

ESTIMATION

Estimation of costs is a forecasting process. The estimator is predicting what the cost will be for some action to be carried out at a future time. There will thus inevitably be variations between the estimate and the actual cost of producing the job. There is a great deal of data, potentially available, which could be used to aid in this forecasting exercise. By collecting and storing the historic data on the actual cost of producing the job, for those enquiries that the company wins, it

would be possible to produce the time series of the errors for each estimator and the distribution of the actuals about the estimates. Some margin ought to be added to the estimate to allow for the inaccuracy in predicting the actual cost. Given the error distribution, this margin can be chosen to be such that there is only an acceptably low probability of the actual cost being higher.

Estimators are well aware of this. They will often say that they are more confident on one particular estimate than another. Clearly the time allowed for the estimation process affects this. The errors, or forecasting performance, may depend upon several factors. A model is proposed that relates this to three types of factor:

i) Estimator's own level of confidence in the estimate: This will be entirely subjective from the estimator and will be his belief. It will encompass the interaction of a range of factors, including the time that he was allowed to do the estimation. This can be in terms of some score on a range 0 to 10, or classes based on likely maximum actual costs as percentage of estimate.

ii) Similarity to earlier jobs: Five different levels of similarity to previous jobs have been defined, size, function of the product supplied, the manufacturing processes needed, raw materials used, and finally a completely new job or product. Several possibilities may apply to the same job.

iii) Experience with the job/product: This will be based on simple classes, a lot of, some, little or no experience in that type of job.

In one particular company, agreement has been reached for some of the estimators to provide this information routinely. Once sufficient data has been collected, analysis will be performed to see how the differences, absolute or percentage or by broad categories, between the actuals and the estimates relate to these factors.

These results will be used to determine an Adjustment Module, to apply to the cost estimates produced. The margin to apply to the estimates will thus depend upon the particular situation, type of enquiry, market and estimator, rather than one fixed value. The adjustment module could be in the form of a mathematical model, a DSS type system or an Expert System. This will depend upon the results of the analysis.

Loading and Producing The Job to Agreed Time

As discussed earlier, estimation is almost always performed on the basis of producing the job at normal standard costs. There is rarely any real attempt to check if and when the job can be carried out and delivered. It is assumed that somehow the promised delivery date will be met or acceptable excuses found. Frequently, companies find that this is not the case. Jobs get delivered later than promised to the customer or several other jobs have to be delayed to meet the important job's delivery date. Overtime may have to be worked and/or work

subcontracted at short notice to complete the job on time. In the first case, the company can gain a reputation for unreliability and poor delivery performance, so having to charge lower prices to compensate for this. In the second case, the cost of producing the job is much higher than estimated, so the company ends up making a loss, which could have been foreseen by proper planning. Many companies do not review the actual costs of individual jobs, particularly the smaller companies, and do not know if they are really making profits until the accountant reports at the end of the year.

It is essential therefore to check the feasibility of being able to produce the order with the current work load at different delivery times and evaluate any extra costs above the standard allowances that will have to be incurred. If this is not done, the cost estimates will not lead to the correct decisions being taken.

An Input/Output planning approach based on the control of a hierarchy of backlogs of work can be used to produce a dynamic capacity planning and loading model to determine the capacity to provide at each work centre in future time periods, allocating overtime, transferring operators, process as split batches etc. This hierarchical backlog control system has been described in earlier papers. {See for example Kingsman, Tsiopoulos and Hendry (1989), Hendry and Kingsman (1991 and 1993) and Hendry et al (1992)}.

For any enquiry, norms for the enquiry preparation time, the time for the customer

to respond, any further design work and for the acquisition of materials and components are set. These may depend on the characteristics of the order itself, the customer and the material supplier. The earliest time the order, if confirmed, could enter the shop floor can then be calculated. The order is assumed to enter the Backlogs of work on all work centres required at this earliest time. The time the operations would have to be completed at each work centre, to meet the agreed delivery date, can be calculated from the set-up and processing times on each of the work centres needed by the enquiry, plus the buffer transfer times between work centres. This will include the time spent in the 'Pool' of jobs in the production planner's office to allow good scheduling of shop floor activities. This can be done for all jobs, no matter where they currently are in the system. Hence for all weeks forward up to the planning horizon, the maximum delivery date to be offered, the input and output of work week by week for all work centres is available.

Considering the Backlog of work to be carried out on the shop floor at any time T forward from now, time 0, in the simplest situation it must satisfy constraints such as the following:

$$\begin{aligned} \text{Backlog}(T+1) &= \text{Backlog}(T) + \\ &+ \text{Input}(T+1) - \text{Workdone}(T) \\ \text{WorkDone}(T) &< \text{Capacity}(T) \\ \text{Cum WorkDone over Periods } 0 \text{ to } T &> \\ \text{Cum Output of Work Required over } 0 \text{ to } T & \\ \text{Backlog}(T) &< \text{Cum WorkDone from } T \\ &\text{to end of Planning Horizon.} \end{aligned}$$

This constraints must be satisfied for

all work centres and all times up to the Planning Horizon. The aim is to ensure that all the work now in the system is completed and delivered before the end of the Planning Horizon. This then gives the maximum delivery time that the company will generally aim to provide. The decision variables of major interest are to determine the Capacity to provide each week at each work centre.

Alternative lead times for an enquiry can be generated by reducing the buffer transfer times, giving priority in processing at work centres over other jobs. The actions to provide extra capacity to ensure the Backlog constraints are satisfied for each alternative delivery date, overtime, moving operators etc., can be costed to add to the normal cost.

DECISION RULES

In stages 1,2 and 4 of the enquiry process, see Figure 1, it has been found that companies use a variety of rules to make their decisions. These rules tend to be informal, qualitative and judgmental. They are not written down, nor systematically applied every time. As illustrated on the right hand side of Figure 1, they rely on variables relating to the company itself, the job, the customer and the market competitiveness. These are for guidance and based on experience. Following interviews and verbal protocol sessions with the management of eight different MTO companies, the researchers have come up with over 50 rules that are used in the four stages, see De Souza (1994).

Further work is needed to clarify the precise detail of these rules. However, they provide the basis for developing an Expert System approach.

QUANTITATIVE ASSESSMENT OF MARKETS AND COMPETITIVENESS

There is a great deal of information that can be used in modelling to aid in this process, particularly in assessing the current level of competitiveness and the likelihood of winning an enquiry with different responses. The outcome, of winning or losing a bid, can be represented as a 0/1 variable. It can thus be treated as a binomial variable. Hence, from the past history of the number of wins and the bids made, it is possible to estimate the mean and variance of the probability of winning the enquiry, assuming a Beta distribution applies.

The total market in which the company competes divides into different sectors with different probabilities of winning. The market sectors depend on factors such as the size of the job, the value of the job, customer type, customer location, industry, new contact or long previous association, length of contract etc. The first step is to define all the factors that might distinguish one market sector from another and to specify the alternative values, or ranges of values, that each factor could take. A Chi-Squared analysis can then be performed to see if there are clusters of values of the factors giving significantly different probabilities of winning. If so, then these give the

different market sectors. A simplified approach of doing a pairwise comparison of adjacent levels in a factor based on a t-Test is used. The enquiries are grouped into four sets, each one containing bids in each of the four quadrants of above and below average for lead time and price bid, usually represented by mark-up on normal cost. In comparing levels for differences, two levels are combined only if there is a significant difference between the probabilities of winning in the tests levels for all four quadrants.

The procedure is organised as a tree search. The factors are ordered on the basis of which has levels with the most significant differences in the probability of winning. Let us assume this is quantity, ordered as in the example of Figure 2. There was no significant difference in the probability of winning an order for order sizes of two or more. There were only two significantly different levels on the order quantity factor, one unit in the order or more than one unit. There was a bigger difference in the probabilities of winning between these two values of the order quantity factor than any other factor. The tree search continues by considering the two groups of bids, the first, orders of size one, and the second, orders of size 2 or more. The analysis is repeated for each group separately as a continued tree search. The outcome in the illustrative example was four market sectors:

1. Orders for only 1 unit
2. Orders for two or more units of value less than £2000, where the company

made a low mark-up.

3. Orders for two or more units of value less than £2000, where the company made a high mark-up.

4. Orders for two or more units of value more than £2000.

There was a probability of winning of 12% for market sector 1, 61% for sector 2, 100% for sector 3 and 18% for sector 4. The high and low mark-ups probably reflect situations where the company concerned had a technological or other advantage. Within a market sector, a similar approach can be used to calculate the probability of winning as a function of the lead time and the price set. All the bids within a market sector are considered and analysed as above, but on the basis of only two factors, price set and lead time. Eight levels, say, are set for each of the two factors and adjacent levels combined if there is no significant difference in the probability. This gives a strike rate matrix. The assumption that the probabilities are beta distributed, leads to simple formulate to update the probabilities over time.

An important and necessary change of emphasis, implied by this approach, is the concentration on the current acceptable market prices for the work required by the enquiry. The profit margin is then given as the difference between the price gained and the cost of producing the order. This is quite different to the currently generally used approach of concentrating on deciding the profit margin to seek. The current approach has the drawback of limiting profits on orders

where the company has a major competitive edge, since doubling or trebling the profit margin is unlikely to be considered, and not focussing attention on reducing costs where the company has a disadvantage.

4. Developing a Decision Support Expert System

The ways the various elements proposed in section 3 will fit into an integrated system for dealing with enquiries is shown in outline in Figure 3. The main inputs of data required, both for the initial set-up and for routine collection will be stored in databases and are as follows:

i) Details regarding the enquiry, indicating whether prices and delivery dates are fixed or negotiable, and other customer information that might be relevant in considering the order. The job routing as configured from the design supplied by the customer is also needed. It can be in a detailed form, specifying the operations and their set up and processing times at individual machines or in a rough-cut form, specifying the operations and associated times by work centres.

ii) Capacity planning information, including details of normal and maximum work centre capacities. The expected workload incurred by other jobs that have already been confirmed, or for which a bid has been made is also needed for capacity planning purposes.

iii) Marketing analysis data. For the purpose of the marketing analysis, the information regarding past enquiries is needed. This will include the characteristics of each enquiry in terms of the different market segments, an indication of whether a bid was made and if so whether it was won or lost. Ideally, up-to-date information on competitors should also be collected and stored.

iv) Finally, information on the estimation process itself, estimators confidence similarity with work and material etc., and the actual costs incurred for jobs that were won.

Much of this data may already be being collected, particularly production data and job routing data, which will be needed for short term production planning and shop loading, for example in an MRP system, as well as the proposed system. The marketing data and the analysis of the estimation process is new. The marketing data used to generate the strike rate matrices, can also be used for other company market analyses.

Two parallel lines of research are being pursued. The first, the more advanced, concentrates on the planning aspects, the capacity planning module, the marketing module and an initial approach to the final decision making on the price and lead time to bid. This is being set up as a Decision Support System. The two main elements of the system, labelled GADDA and STRAP in Figure 3, can be used simultaneously to carry out the tasks of

generating alternative delivery date responses and generating the relevant strike rate matrix respectively. These, plus the cost estimates, provide the input into EDMA, the determination of the bid to make.

STRAP: The marketing analysis assesses past enquiries to generate a set of matrices indicating the probability of winning orders according to the price and lead time quoted. Given information regarding the specific enquiry, the output for this element will be the appropriate matrix for this type of job.

GADDA: The element which generates alternative delivery dates uses production planning routines to assess if and when the order can be fitted into the workload of the factory. If the customer has specified a delivery date, then the time frame is considered as fixed and the task is to determine whether sufficient capacity is available or can be provided to complete the new enquiry in addition to other jobs that have already been confirmed for that time period. If not, then it is assumed that the job should be completed as soon as possible. In most cases, there will be a set of feasible delivery dates, each requiring different capacity levels and assuming a different priority for the enquiry. Thus the output from this element will be a set of feasible delivery dates. The 'cost' of achieving each date in terms of job priority and any capacity adjustments will be indicated in terms of the necessary actions such as work overtime, reallocate operators and split batching.

EDMA: This module collates the output from the GADDA with that from STRAP. The system user is then presented with a set of alternative responses to enquiries. For each response, the probability of winning the bid along with the production implications and costs are indicated. This module is interactive. It does not attempt to determine the optimal bid, rather it presents information for the user to make an informed choice. The output of this element will be a decision regarding whether to make a bid and if so the price and delivery date to quote. The user can investigate each of the options further if required. For example, the impact a DD would have on the workload can be examined graphically, and alternative ways of adjusting the capacity whilst attaining the same DD could be generated by the user.

The precise form that EDMA will take will also be part of the other line of research, the use of judgmental decision rules.

The other more recent line of research is on The Estimation Module, including the initial evaluation and deciding how to prepare the cost estimates. The research on the actual estimation process is attempting to see if the variation in accuracy in predicting the final cost outcome can be related to factors known at the time the estimate was made. Hence, some mathematical or statistical model might be combined with judgmental rules to improve the accuracy of the estimation process for pricing purposes. On the other aspects, as discussed in section 3, the

concentration is on identifying the decision rules used by MTO companies at each stage of the enquiry process, in order to evaluate whether some form of Expert System would be helpful. It may be possible to relate these judgmental rules to the particular market the MTO company aims to serve, international, national or regional, capital goods, subcomponents or service work for example.

The nature of the link between the system proposed, particularly the DSS part, and other production planning functions will depend on the other systems that a company has in place. In terms of the general manufacturing planning and control system of Vollmann et al (1988, page 16) the DSS would be used at the front end to carry out the demand planning and generate the master production schedule.

5. SOME RESEARCH ISSUES

5.1 Level of Aggregation of Entities in System

It is envisaged that the system will be used either interactively at the tender vetting (bid/no bid) committee meeting, which makes the final decision on responding to a customer enquiry, or in the preparation for such a meeting. If an enquiry is not considered important enough to hold a bid/no bid meeting, it is anticipated that it would be used by the person responsible for responding to the enquiry. In either case, the relevant parts of the proposed system have to allow the

manager or committee to examine the implications of alternative courses of action in real time, so it must operate quickly. On the other hand, the underlying model has to represent the factory sufficiently well to make acceptable predictions of the outcome of any plan. In general, if too much information is used, it is difficult for the system user to take in all the information and to compare alternative solutions. Thus a major issue is the level of aggregation of entities to use in the system.

The level of aggregation that is appropriate will depend upon the time scales involved, the complexity of the product and the complexity of the factory layout. The time scale will depend on the company's manufacturing lead times and the average delay between the arrival of an enquiry and the confirmation by the customer. It is anticipated that an appropriate aggregated time unit will be a week, at least for the two collaborating companies in this project. In other cases, fortnightly or monthly units may be more appropriate but smaller time units are unlikely to be required at the medium term planning stage.

In terms of factory layout, machines can usually be grouped into work centres either on the basis of their process function or on the basis of the product family that they process. In such cases, planning can be carried out at the work centre level. It is unnecessary to plan work at individual machines when using weekly time units and/or aggregated bills of material. A work centre in general can be defined in several ways. It can be defined

as a set of facilities that carry out a specific process when any of these facilities can be used to process any type of product. However, sometimes it is necessary to break such groups of machines into subsets if, for example, some of the machines must be used for products of one type of raw material and the other machines for products made of another type of raw material. If production is organised as a series of work cells, where each work cell has several processes in line with no queuing between intermediate machines, then the work cells will be the work centres to use in the system.

5.2 Stability of System and Interaction with Buffer and Priority Norms

A further question is clearly how well the proposed planning and control system will achieve the objectives of securing a more profitable mix of orders and a more reliable delivery performance. One way of giving short lead times is to allow some orders to have priority at work centres, not having to queue for the normal time. However, as the proportion given such priority increases, then control is lost. How the system reacts to differing limits on the proportion of work given priority needs to be explored. The size of the buffer transfer norms between work centres and the buffers on material delivery and customer confirmation times will also affect the performance of the system. Other similar issues are the behaviour of the system in the face of varying enquiry arrival patterns, sudden booms and slumps in orders.

A system simulation model has been developed for the companies collaborating in the research to explore these issues. Whilst giving general guidelines on the level of aggregation to use, the research cannot provide specific answers to every particular situation. The simulation programme can also assist in this task. It provides a basis for any future user to assess the performance of the DSS in that user's specific situation. It is envisaged that the simulation will be used prior to implementation to determine the appropriate level of aggregation for that company.

The overall structure of the system simulation is shown in Figure 4. It contains a shop floor factory simulator especially formulated for MTO situations. The system only simulates the planning modules, not the estimation modules. A set of 'jobs' needs to be generated for processing through the simulated factory. A 'job' is defined as a particular number of units of a product requiring a particular set of processes in a particular sequence. They are intended to represent the typical types of work the particular company investigated receives. The database of past enquiries contains a wide variety of such jobs. Manager's views as to whether other 'jobs' are likely to occur and whether any significant changes in the part of 'jobs' is likely in the future will be included. Future enquiries will be generated as appropriate random samples of this 'database of jobs'. Each enquiry that comes in will be, examined using GADDA, STRAP and EDMA as described above.