The use of knowledge-based Genetic Algorithm for starting time optimisation in a lot-bucket MRP

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Abstract. In production planning, Material Requirement Planning (MRP) is usually developed based on time-bucket system, a period in the MRP is representing the time and usually weekly. MRP has been successfully implemented in Make To Stock (MTS) manufacturing, where production activity must be started before customer demand is received. However, to be implemented successfully in Make To Order (MTO) manufacturing, a modification is required on the conventional MRP in order to make it in line with the real situation. In MTO manufacturing, delivery schedule to the customers is defined strictly and must be fulfilled in order to increase customer satisfaction. On the other hand, company prefers to keep constant number of workers, hence production lot size should be constant as well. Since a bucket in conventional MRP system is representing time and usually weekly, hence, strict delivery schedule could not be accommodated. Fortunately, there is a modified time-bucket MRP system, called as lot-bucket MRP system that proposed by Casimir in 1999. In the lot-bucket MRP system, a bucket is representing a lot, and the lot size is preferably constant. The time to finish every lot could be varying depends on due date of lot. Starting time of a lot must be determined so that every lot has reasonable production time. So far there is no formal method to determine optimum starting time in the lot-bucket MRP system. Trial and error process usually used for it but some time, it causes several lots have very short production time and the lot-bucket MRP would be infeasible to be executed. This paper presents the use of Genetic Algorithm (GA) for optimisation of starting time in a lot-bucket MRP system. Even though GA is well known as powerful searching algorithm, however, improvement is still required in order to increase possibility of GA in finding optimum solution in shorter time. A knowledge-based system has been embedded in the proposed GA as the improvement effort, and it is proven that the improved GA has superior performance when used in solving a lot-bucket MRP problem.

1. Introduction
In manufacturing planning and control, Master Production Schedule (MPS) is widely used to schedule end items production. MPS plays important roles especially in Enterprise Resource Planning (ERP) [1]. Production lot in MPS would be derived further to be Material Requirement Planning (MRP) [2]. Because MPS is an almost fixed production schedule, then production time period is arranged for shorter period, and usually weekly instead of monthly. Therefore, MRP must be arranged based on weekly time period as well. In order to represent time phasing, an MRP system is usually developed based on time-bucket system, it means that period in the MRP is representing the time and usually weekly. Production evaluations, such as inventory analysis, planned order receipt and so on, would be conducted every end of period. Time-bucket MRP could be implemented successfully in Make To
Stock (MTS) company, which must finish the production before customer demand is received. It is different with Make To Order (MTO) company, which receive order from customers with specific quantity and due date. Production activity would be started only after the order was received.

MTO company still need to arrange an MRP to schedule production or order of the required materials. Therefore, in order to be successfully implemented in MTO company, a conventional MRP system is need to be modified. Fortunately, there is a modified MRP system, which called as lot-bucket MRP, proposed by Casimir in 1999 [3]. In the lot-bucket MRP system, a bucket is representing a lot, and the lot size is preferably constant. The time to finish every lot could be varying depends due date of lot. As a detail production plan, starting time of a lot must be determined precisely by considering the reasonable production time. So far there is no formal method to determine starting time in the lot-bucket MRP system. Trial and error process usually used for it but some time it causes several lots have very short production time and the lot-bucket MRP would be infeasible to be executed.

Determination of starting time of lot in lot-bucket MRP system could be viewed as optimisation case. The objective function is to maximise reasonability and acceptability index of the lot-bucket MRP system with decision variable is the starting time itself. Reasonability index would be higher when production time is shorter, but there is no slack and idle time. When there is slack and or idle time, actually the slack and idle time could be used to prolong the production time. Consequently, starting time of the lot must be revised. Acceptability index would be higher if the production time after being prolonged by reducing slack and idle time is longer than minimum production time allowed. In order to find optimum starting time of lots, a searching algorithm could be utilised. This paper presents the use of Genetic Algorithm (GA) for optimisation of starting time in a lot-bucket MRP system. Even though GA is known as powerful searching algorithm, however, improvement is still required in order to increase possibility of finding optimum solution in shorter time. A knowledge-based system has been embedded in the proposed GA as the improvement effort. Further, such GA is called as knowledge-based GA (KB-GA). Through a case study, it is proven that the KB-GA has superior performance when being used in solving a lot-bucket MRP problem.

2. Related works

Main reference of this study is a paper about lot-bucket MRP system that authored by Casimir in 1999 [3]. In such paper, there are a lot of useful information about lot-bucket MRP development, such as the lot-bucket MRP system could be implemented in Just In Time (JIT) manufacturing and constant lot size is representing container capacity in JIT manufacturing or could be determined based on average order. The production time is represented with value 1 (normal production time) and less than 1 (faster production time). This study also use such information in optimising the starting time in lot-bucket MRP.

Study about MRP has been conducted by several previous researchers with different manufacturing condition. In conventional MRP, production or order lead time is assumed constant. In real situation, when the lead time is not constant and the variation is relatively big, then a technique to deal with the uncertainty lead time is required. Diaz-Madronero et al. (2015) have investigated the use of fuzzy multi-objective integer programming to develop MRP system under fuzzy lead time [4]. The fuzzy multi-objective integer programming is used to maximise satisfaction degree of three objectives which are minimisation of cost, back order quantity and idle time. Such study also discuss about a case study to proof that the proposed technique could work well in solving considered case. Similar study that deal with uncertainty factors and solved using fuzzy technique could be seen in detail in [5].

Another study that deals with lead time in MRP system has been conducted by Milne et al. (2015) [6]. In such study, values of planned lead time were the main decision variable. A Mixed Integer Programming (MIP) was proposed as the optimisation of the planned lead time values by considering a set of constraints contains component and capacity constraints. Objective of the optimisation is minimising variety of costs or penalties. To test performance of the proposed method, a set of real data from an electronic industry was used. Dynamic lead times were represented by minimum and
maximum lead time values. Based on the case study, it is proven that the proposed method could work well even though with heavy computation load due to the binary variables. Similar studies that concerned with the weakness of constant lead time and time periods assumption in MRP have also been conducted by previous researches [7], [8], [9].

Studies about time-bucket MRP that concerned with lot sizing have also been investigated by previous researchers. In time-bucket MRP, the lot sizing system could be viewed as multi-products and multi-periods inventory system because MRP is product's parts management for several production periods. Lot sizing for reversed MRP has been investigated by previous researchers [10]. Reversed MRP accommodates disassembly operation that not accommodated in conventional MRP system. In reversed MRP system, demand is not only from end item, but also from parts that have independent demand. Another study that investigated lot sizing in time-bucket MRP could be seen in detail in [11]. Such study used a mathematical model to develop an optimum lot sizing model.

3. Knowledge extraction in lot-bucket MRP

In this study, there is only one knowledge that would be extracted from lot-bucket MRP system. The knowledge is understanding when problems would be occurred in a lot-bucket MRP system. A problem related to sufficiency production time would be occurred when interval between 2 consecutive time requirements is relatively short but the customer order is relatively high. In such condition, the production time might be very short and it could cause the lot-bucket MRP system unacceptable. Basically that condition could be anticipated when in the previous lot there are idle or slack times that could be used to prolong the unacceptable production time. Therefore, the knowledge to be extracted is, if there is a lot with shorter production time and below minimum limit of production time allowed, then the production time would be prolonged by reducing slack and idle time of the previous lot.

4. Mathematical model development

Decision variable in this study is starting time of each lot in a lot-bucket MRP system so that the lot-bucket MRP system is reasonable and acceptable. Therefore, the objective function is to maximise sum of reasonability and acceptability index of all lot as formulated in equation (1).

\[ Z = \sum_{i=1}^{L} R_i + \sum_{i=1}^{L} A_i \]  

(1)

Constraints to get a feasible solution are as follows:

\[ R_i = \begin{cases} 1, & \text{if lot } i \text{ is reasonable} \\ 0, & \text{otherwise} \end{cases} \]  

(2)

\[ A_i = \begin{cases} 1, & \text{if lot } i \text{ is acceptable} \\ 0, & \text{otherwise} \end{cases} \]  

(3)

\[ Sl_i = S_i - d_{i-1} \]  

(4)

\[ I_i = d_{i-1} - c_i \]  

(5)

\[ c_i = S_i + P_i \]  

(6)

\[ P_i = \begin{cases} 1, & \text{if lot size of lot } i \geq \text{customer order} \\ \text{lot size of lot } i / \text{customer order}, & \text{otherwise} \end{cases} \]  

(7)
where:

\[ Z \] : objective value \\
\[ R \] : reasonability index of a lot \\
\[ A \] : Acceptability index of a lot \\
\[ i \] : lot index \\
\[ L \] : number of lot \\
\[ S_l \] : slack of a lot \\
\[ S \] : Starting time of a lot \\
\[ I \] : idle time of a lot \\
\[ d \] : due date of a lot \\
\[ c \] : completion time of a lot \\
\[ P \] : production time of a lot

Equation 2 and 3 will set reasonability and acceptability of a lot to 1 if the lot is reasonable or acceptable, or to 0 if otherwise. Equation 4 is the formula to determine slack time of a lot, which is difference between starting time of a lot with due date of previous lot. Equation 5 is the formula to determine idle time of a lot, which is the difference between due date and completion time of the lot. Equation 6 shows the formula to determine completion time of a lot while equation 7 shows the formula to determine production time.

5. Genetic Algorithm development

5.1 Chromosome representation

The chromosome would represent starting time of every lot. The numeric type for such solution would be real time, instead of integer, in order to get precise solution. In the chromosome, there are several locus. The first locus is representing starting time of the first lot, while other locus is representing the difference between starting time of the related lot with the previous lot. Figure 1 shows the chromosome when there are 7 lots and representing starting time of lots 0, 0.83, 1.83, 2.83, 3.73, 4.73 and 5.6. Fitness function of the chromosome is \( Z \) (equation 1).

![Figure 1. Chromosome representation](image)

5.2 Crossover mechanism

In this study, a simple one-cut point crossover operation is implemented. Such crossover operation would cut both of parent chromosomes and interchanges part of the chromosomes each other. Figure 2 shows the mechanism of such crossover.

![Figure 2. Crossover mechanism](image)
5.3 Mutation mechanism

Mutation proposed in this study is random step mutation. First, GA would select chromosomes to be mutated based on mutation probability. Then, from the selected chromosomes, GA would select one or more than one locus randomly. The selected locus, their value, would be changed by step up or down randomly. The step value is based on a delta (\( \Delta \)) value and in this study the delta value is between 0.01 to 0.20. Such mutation operation enables the KB-GA to explore solution domain step by step. The mutation mechanism could be formulated as shown in equation (7).

\[
l' = \begin{cases} 
    l + \Delta, & \text{if } s \ (\text{randomly defined}) \text{ is } 1 \\
    l - \Delta, & \text{otherwise}
\end{cases} 
\]  

(7)

where:
- \( l' \) : new locus value
- \( l \) : old locus value

6. Case study

Performance evaluation of the proposed KB-GA is carried out by applying it to solve a lot-bucket MRP problem. There is a product with 4 parts that divided into 2 levels. The product structure is shown in figure 3 while due date of every lot and other relevant data is shown in table 1. Minimum production time allowed is 0.8, it means that the production could be speed-up maximum at 20% above normal time. A comparison study with a conventional GA was also conducted to show superiority of the KB-GA.

![Figure 3. Product structure](image)

**Table 1. Data of lot**

| Lot | 1   | 2   | 3   | 4   | 5   |
|-----|-----|-----|-----|-----|-----|
| Order quantity | 100 | 80  | 130 | 90  | 100 |
| Due date       | 3   | 4.30| 5   | 5.90| 7   |

The KB-GA has been ran for 500 generations, with crossover and mutation rate is 0.3 and 0.2 respectively. Actually, GA has been ran several time to ensure that KB-GA could provide stable solution. Parameter to stop the KB-GA at 500 generations is when there is no improvement anymore for minimum half number of generation. KB-GA provided solution as shown in table 2 to table 6.

**Table 2. Lot-bucket MRP for final product (A)**

| Lot number | 1   | 2   | 3   | 4   | 5   |
|------------|-----|-----|-----|-----|-----|
| Time requirement | 3.00| 4.10| 5.00| 5.90| 7.00|
| Schedule receipt | 0.00| 0.00| 0.00| 0.00| 0.00|
| Projected slack time | 0.00| 0.00| 0.00| 0.00| 0.00|
| Projected idle time | 0.00| 0.10| 0.00| 0.00| 0.10|
| Projected production time | 1.00| 1.00| 0.90| 0.90| 1.00|
| Planned starting time | 2.00| 3.10| 4.10| 5.00| 6.00|
Table 3. Lot-bucket MRP for part (B)

| Lot number | 1   | 2   | 3   | 4   | 5   |
|------------|-----|-----|-----|-----|-----|
| Time requirement | 2.00 | 3.10 | 4.10 | 5.00 | 6.00 |
| Schedule receipt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected slack time | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected idle time | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| Projected production time | 1.00 | 1.00 | 1.00 | 0.90 | 1.00 |
| Planned starting time | 1.00 | 2.10 | 3.10 | 4.10 | 5.00 |

Table 4. Lot-bucket MRP for part (C)

| Lot number | 100 | 80  | 130 | 90  | 100 |
|------------|-----|-----|-----|-----|-----|
| Time requirement | 2.00 | 3.10 | 4.10 | 5.00 | 6.00 |
| Schedule receipt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected slack time | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected idle time | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| Projected production time | 1.00 | 1.00 | 1.00 | 0.90 | 1.00 |
| Planned starting time | 1.00 | 2.10 | 3.10 | 4.10 | 5.00 |

Table 5. Lot-bucket MRP for part (D)

| Lot number | 100 | 80  | 130 | 90  | 100 |
|------------|-----|-----|-----|-----|-----|
| Time requirement | 1.00 | 2.10 | 3.10 | 4.10 | 5.00 |
| Schedule receipt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected slack time | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected idle time | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| Projected production time | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 |
| Planned starting time | 0.00 | 1.10 | 2.10 | 3.10 | 4.10 |

Table 6. Lot-bucket MRP for part (E)

| Lot number | 100 | 80  | 130 | 90  | 100 |
|------------|-----|-----|-----|-----|-----|
| Time requirement | 1.00 | 2.10 | 3.10 | 4.10 | 5.00 |
| Schedule receipt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected slack time | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected idle time | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| Projected production time | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 |
| Planned starting time | 0.00 | 1.10 | 2.10 | 3.10 | 4.10 |

Based on the result above, it could be analysed that no slack and idle time when production time is less than 1 and production time of all of the lot is not less than minimum production time allowed. It means that the lot-bucket MRP is reasonable and acceptable.
7. Discussions
To show superiority of the proposed knowledge-based GA, a conventional GA has been ran as well with same parameter values as in the KB-GA, and it provided a solution as shown in table 7 (for lot-bucket MRP of final product only).

| Lot number | 1  | 2  | 3  | 4  | 5  |
|------------|----|----|----|----|----|
| Time requirement | 3.00 | 4.30 | 5.00 | 5.90 | 7.00 |
| Schedule receipt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected slack time | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Projected idle time | 0.00 | 0.30 | 0.00 | 0.00 | 0.10 |
| Projected production time | 1.00 | 1.00 | 0.70 | 0.90 | 1.00 |
| Planned starting time | 2.00 | 3.30 | 4.30 | 5.00 | 6.00 |

It could be seen that there is an unacceptable production time, which is production time of lot number 3 that bellow minimum production time allowed. However, the previous lot has long idle time, which is 0.3. Actually, the idle time of the previous lot could be used to prolong the unacceptable production time to make it acceptable.

In the knowledge-based GA, effect of the extracted knowledge is revision of the time requirement of second lot of final product (A) from 4.3 to 4.1. It would reduce the idle time of lot number 2 from 0.3 to 0.1 to prolong production time of lot number 3 from 0.7 to 0.9 and become acceptable. However, such solution would affect to holding cost for lot number 2. It would be finished at 4.1 but would be delivered at 4.3. If the holding cost is not significantly affects the production system performance, then the solution provided by the KB-GA is better because it could avoid potential production failure of lot number 3 due to unacceptable production time.

8. Conclusion and suggestion
Based on explanation above, it could be concluded that lot-bucket MRP problem could be viewed as optimisation case and GA could be one of alternative algorithm for finding the solution. Even though GA is powerful, however, improvement of the searching process is still required, especially when faced problem is complicated. In this study, it was proven that a knowledge-based system could be used to improve GA's searching process. Performance of the knowledge-based GA is superior compared to conventional GA when being used to solve a lot-bucket MRP problem.

With refer to the discussions above, for further research, it is suggested to consider costs that involved in the production planning such as holding cost and cost to speed-up production time. Consideration of costs would make the proposed solution more practical in real world industry.

From the GA side, as the optimisation tool, chromosome encoding technique would affect to the effectiveness of the GA when searching the solution. For instance, in this case, if the chromosome uses binary number, starting time of the lots might be very precise. However, the searching process inside the GA would be not effective because of larger solution domain. Trade-off between precise solution and computation effective could be interesting analysis for academic world.

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