Abstract

The target of this research is to address scheduling problems in order to ship multi-item orders in a rice milling process on the same day the order is placed. Milled rice can be stored as stock for some days and can be shipped from stock to satisfy orders. The setup time for switching milled items are needed and work hours in a day are given in the process. Scheduling is generated from the producers’ order forecast, orders and stock before milling. When new orders during milling (urgent orders) come and exceed the work-in-process stock, the schedule must be modified in order to satisfy the orders. The purpose of this problem is to minimize the number of over time hours worked, to reduce switching time and to maximize throughput. In this problem, because urgent orders account for 90% of the whole, stocks often run out and the need to mill new items often occurs in multi-items.

Therefore, this research proposes a modifiable scheduling method to minimize the number of switches and over time hours worked when milling starts in a day and when urgent orders are received. In scheduling, items to be milled and the amount to mill are first decided using an inventory control theory. The milling sequence is decided using “modifiability”, which is defined by the reductibility of milling time and the necessity of modification of items to be milled for modifiable scheduling against urgent orders. In a case where the estimated end time runs over work hours, milling amounts which has smaller stock-out probability are reduced in order of increasing.

The proposed method has been applied to a real problem. It has been confirmed that this method can generate the solutions 37% better than producer’s solutions.

1. Introduction

In a production field, effective scheduling plays an important role. Such schedules are created by human experts and take many hours, but thanks to computer progress, rapid automated scheduling using a computer has been introduced.

The target of this research is to address scheduling problems of a multi-item rice milling process. Milled rice can be stored as stock for some days and can be shipped from stock to satisfy orders. Ordered items must be shipped on the same day that the order is placed. When switching milled items in a milling machine, some setup time is necessary. Work hours in a day are also given in the process. Under these constraints, scheduling is generated from the producers’ order forecasts, the orders and the stock before milling. When new orders during milling (urgent orders) come and these orders cause an excess of work-in-process stock, the schedule must be modified in order to satisfy the urgent orders. The purpose of this research is to minimize the number of overtime of hours worked, to reduce switching time and to maximize throughput.

Currently, producers forecast the main items in urgent orders based on empirical knowledge and adjust the schedule of stock to make against each order from the forecast and the current stock. However, many urgent orders still occur that vary from the order forecast. So, when the amount of urgent orders exceeds amount to mill, it is necessary to mill repeatedly in order to make up the lack of stock, and when work-in-process amount to mill exceed the amount of orders, the excess milling needless items takes time. Then, the number of switches increases and overtime occurs.

“Reactive scheduling” or “real-time scheduling”, is where an initial schedule is created in an ideal environment and is modified by a rule to modify when the environment changes[3, 4]. In these researches, the methods of acquiring, comparing and evaluating the rules have been reported. However, the initial scheduling prior to environmental changes has not been discussed enough. Because the productivity of a modified schedule depends on
the schedule before modification, a rescheduling method that maintains productivity after modification due to environmental changes is necessary.

In this target problem, the amount of orders in 5/6 items of a whole items is too few to hold much stock. Therefore, the schedule of items to be milled and amount to mill has to be adjusted to accommodate urgent orders, in order to effectively mill in a limited operational capability. In this research, the proposed modifiable scheduling method can effectively minimize the number of switches and the amount of overtime hours worked when urgent orders cause work-in-process stock.

For scheduling, it is necessary to decide what items to mill, the amount to be milled and the milling sequence. The amount of milled items required to be in stock is decided using an inventory control theory[1, 2, 5] that prevents stock-out. The items included in the safety stock( enough stock to prevent stock-out) are decided by the experts’ order forecast and have to be milled to boost the stock up to the limited stock decided by forecast. When the sequence of items to be milled is decided, attention must be focused on reducing the amount of milling time and making any necessary modifications to the items, to address urgent orders late in the working day. From these two characteristics, “modifiability” is defined and the milling sequence is decided. The items that has smaller modifiability are milled earlier. In a case where the end time of the schedule is after the given work hours, amount to mill that has a larger stock-out margin is reduced.

2. A Scheduling Problem in Multi-item Production

2.1. Outline of the problem

The target of this research is to solve a scheduling problem whereby multi-items in a rice milling process can be shipped on the same day that orders are placed(Figure 1). Milled rice can be held in stock for some days and can be used to fill orders to be shipped from the stock, but expired stock must be discarded. The setup time is needed to switch milled items and the work hours in a day is given in the process. The initial schedule is generated from the experts’ order forecast, the outstanding orders and the milled items already in stock. When new orders arrived during milling(urgent orders) which exceed the work-in-process stocks(stock+amount of milling item), the schedule has to be modified in order to complete the orders. The evaluation factors of this problem are to minimize the number of overtime of hours worked and the number of machine setting switches, and to maximize throughput. The purpose of this problem is to generate highly-evaluated schedules that satisfy these constraints as well as ensuring that all orders received in a day are shipped on the same day they were placed.

The experts can forecast the main items that make up the majority of orders. They then input the “stock data”, the “order data”, and the “order forecast by experts” into the system. “Order data” consists of the ordered item, the number of items in the order and the time. Since “order data” is generated by accepting the order, “order data” cannot be included in the schedule before the order is accepted. The order forecast consists of the following two factors:

![Figure 1. Outline of the problem](image)

- The average number of main items in the order forecast
  Experts can forecast the number of main items contained in the weeks order to 1/6 of the whole items using their expert knowledge and the past order history. Therefore, the average amount in the weeks is input.

- The average number of total orders
  Experts can forecast the amount of orders that will occur in a day from the average total amount of past orders. Therefore, an average total amount of orders is input.

2.2. Constraints

Scheduling for the mill has the following constraints:

- Order constraints
  All orders received in a day must be shipped the same day.

- Constraints regarding the unit amounts to be milled
  The amount to mill has to be multiples of a given unit amount.

- Constraints regarding the probability of stock expiring
  The expired stock rate has to be below a given proportion.

2.3. Evaluation factors

The target problem for the evaluation is the last schedule for each day of the week. There are three evaluation factors:
1. Minimizing overtime $(T)$
   To minimize the number of overtime hours worked in a week.

2. Minimizing the number of switches $(N)$
   To minimize the number of switches made. Each switch takes ten minutes and requires labor.

3. Maximizing throughput $(S)$
   To maximize the throughput amount of the mill per hour.

The following evaluation function is defined as the weighted $(w_j)$ sum of the above three evaluation factors in this problem.

\[
\text{evaluation function} = -w_1 \times T - w_2 \times N + w_3 \times S
\]

The purpose of scheduling is to maximize the value of the evaluation against the executed schedules.

2.4. Characteristics of this problem
In this problem, the following problems are caused by many urgent orders, which account for 90% of the total number of orders (Figure 2):

- The increase of repeatedly switching items to be milled.
  When the amount of urgent orders to be filled exceeds the amount of milling that was based on the order forecast, it is necessary to repeatedly mill the same item to make up for the lack of stock.

- The excess of hours worked overtime milling items for urgent orders.
  When the amount of urgent orders is lower than amount to mill, unnecessary milling over urgent orders on the day that the orders occur requires time.

- By urgent orders, amount to mill is over amount of order.
- Many Urgent Orders
- Customer P
- Product A:100kg
- Product B:50kg
- Modify
- Start
- End
- Overtime occurs.
- The number of switches increases.

Figure 2. Characteristics of this problem

3. A Scheduling Method Based on Job Modifiability

3.1. Approach
In order to cope with the difficulties mentioned in section 2.4, the scheduling method must respond to urgent orders in order to avoid stock-out and overtime. Therefore, both the items to be milled and the amount to be milled are decided to avoid stock-out, and modifications are then made to avoid overtime. The issue in repeatedly modifications is that the current schedule must be effectively modifiable. In this paper, a method for deciding the milling sequence in a modifiable schedule is proposed. The method for deciding items to be milled, amount to be milled, and the milling sequence is as follows:

1. Deciding what items to be milled and amount of mill
   This method decreases the incidence of stock-out using an inventory control [1, 2, 4] based on stock-to-make. In this problem, it is difficult to estimate the order amounts of each items from the past order amounts, because urgent orders often occur. Therefore, the main items are milled to maintain stock levels using order forecast, while sub items are milled to make up for amount of a stock-out.

2. Deciding the process sequence of items to be milled
   As mentioned in section 2.4, the schedule can’t be modified before the incidence of urgent orders. Therefore, “modifiability” is defined by the reductibility of milling time and necessity of making modifications. In deciding the process sequence of items to be milled, an item with the larger modifiability is milled later in order to generate a modifiable schedule.

3. Reducing item to be milled and the amount to be milled
   Sometimes, the amount of milling required for stock-to-make is great and more milled items are added because of urgent orders. Therefore, the items to be milled and amount to be milled are reduced in order to decrease overtime and the number of switches and to minimize incidence of stock-outs.

In the following section, we describe the details of this method.
3.2. A method for deciding items to be milled and amount of mill using inventory control theory

In the above method, items to be milled and the amount to be milled are decided using inventory control theory. Therefore, in deciding what items to be milled and the amount to be milled, different methods are used for the main items and the sub items.

1. Main items

In inventory stock theory, “safety stock” is introduced, which statistically avoids stock-out against orders while following normal distribution. Safety stock is defined in the following formula, where \( k_s \) indicates the constant “service level” (the acceptable fill rate) and \( \sigma \) is standard deviation of past orders.

\[
safety\ stock = Q_d + k_s \cdot \sigma
\]

Next, the “acceptable maximum stock” is defined as stock limits to avoid expired stock. It is defined in the following formula, where \( k_L \) is the “acceptable expire coefficient” decided by acceptable rate of expired stock, and \( d \) is the maximum stock period.

\[
acceptable\ maximum\ stock = d \cdot Q_d - k_L \cdot \sigma
\]

In order to avoid a stock-out, the main items are kept in larger amounts than safety stock. Therefore, using these formulas, the items to be milled and amount to be milled are decided as shown in Figure 3.

- Items to be milled
  Items whose current stock level is below the safety stock level are milled.

- Amount to be milled
  The milling amount of each item to be milled is decided using the following formulas:

\[
amount\ to\ be\ milled = acceptable\ maximum\ stock - current\ stock - total\ amount\ of\ current\ orders
\]

2. Sub items

Safety stock and acceptable stock are “0” in sub items. The amount to be milled is calculated using the following formula to replenish the reduced amount of an out-of-stock item:

\[
Amount\ to\ be\ milled = current\ stock + order\ amount
\]

3.3. The method for deciding the milling sequence based on job modifiability

The quality of a modified schedule depends on the milling sequence, so it is necessary to decide on a milling sequence that allows for flexible modifications to be made to a schedule to accommodate urgent orders at any time. Therefore, items which have a small level of milling time reducibility or a small rate of modification necessity, are milled earlier in order to allow for adjustments to be made to accommodate urgent orders. Such items are explained in the following way:

- A small level of milling time reducibility
  As mentioned in section 3.2, because larger stock amounts of main items are kept as safety stock, the amount of milled of large safety stock items is large. Large safety stock items require more milling time(Figure 4). Therefore, such items goes to be milled earlier.

- A small rate of modification necessary.
  As shown in Figure 5, it is not efficient to repeatedly mill items that have already been milled because the number of switches increases. Therefore, to avoid milling items repeatedly, those that have a large stock-out margin(= prospective stock - amount of orders) are milled earlier.

In order to decide the milling sequence based on the above characteristics, items which have in smaller rate of modifiability, defined in the following formula, are milled earlier:

\[
modifiability = -safety\ stock - stock-out\ margin
\]
3.4. A method for reducing items to be milled and amount of milling required

In the final phase of working hours in a day, items that are out-of-stock due to urgent orders must be added to the schedule, and an excess of working hours then occurs. Therefore, a method that allocates time margins for urgent orders is proposed, in order to reduce the excess of working hours. When an excess of working hours occur, a time margin is allocated by reducing the amount of milling of the larger stock-out items (Figure 6).

The time margin is decided using the “Average amount of total orders”. Milling performance indicates the amount the milling process can mill in one minute.

\[
\text{time margin} = \frac{\text{work hours}}{\text{milling performance}} - \frac{\text{ave. amount of total orders}}{\text{milling performance}}
\]

Figure 6. Allocation of time margin

When an excess of working hours occurs, the amount of milling is reduced using the following process:

1. In order to keep the stock of main items above safety stock level, amount of the largest stock-out margin for item is reduced using the following formula (Figure 7):

Figure 7. Reduction in amount of mill

2. When the time margin can be allocate (time margin ≤ work hours – end time) as the result of recalculating the end time, this process is finished.

3. If the items that can be reduced (safety stock < stock-out margin + amount of mill) remains, the process goes back to 1. Otherwise, the process goes on to 4.

4. The larger stock-out margin items are deleted. This process is not performed on items whose stock-item margin is over 0 or whose time margin can be allocated.

4. An Application to a Practical Problem

The proposed method has been applied to a practical problem in order to verify its effectiveness of the method.
the proposed method are illustrated. The number on the schedule in Figure shows the item ID.

From the results of Table 2, in each evaluation factor, overtime, the number of switches and throughput, the results of the proposed method are superior to the experts’ method. From Figure 8–10, the methods for deciding what items to mill, amount to mill, and the milling sequence is verified as follows:

### Table 2. Comparing evaluation

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<td>throughput(kg/h)</td>
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</table>

- A method for deciding the amount to mill

As shown in Figure 8, amount of items to mill using the proposed method is larger than that of the experts, so the number of switches decreases. It is confirmed that a proposed method can decide the appropriate amount to mill.

- A method for deciding the milling sequence of items

As a result of the schedule made by the producers in Figure 8, item “7” is processed first and earlier than item “2” in experts’ schedule, but it is not milled in the schedule made by the proposed method. From Figure 9, in the initial schedule made by the proposed method, item “7” is allocated but the following item “2”, which has more safety stock. During the processing of item “2”, because there are few orders for item “7” and there are other urgent orders, the low-priority item “7” is deleted and is milled the next day (Figure 10). It is confirmed that the proposed method can decide an effective milling sequence to reduce the number of switches. Therefore, the effectiveness of the proposed method in this research can be confirmed.

### 5. Conclusion

In this problem, because urgent orders account for 90% of the whole, stocks often run out and the need to mill new item occurs in multi-items. This research proposes a modifiable scheduling method to minimize the number of switches and the amount of overtime worked when milling starts in a day and when urgent orders are received that exceed the work-in-process stock. In this research, a scheduling method is proposed for a milling process that produces multi-items and that adjusts to accommodate urgent orders based on job modifiability. The items to be milled and amount to mill are decided based on an inventory control theory. The milling sequence is decided using modifiability. The proposed method was applied to a real problem. It was confirmed that the proposed method can generate solutions 37% more effective than the experts’ solutions.

### References


