1. Introduction

In recent years, customers’ needs have diversified because of their stronger orientation toward a product and its individualization. In addition, there are concerns regarding environmental, security, and safety issues. In response, manufacturing industries must have high-mix low-volume production systems. From the corporate value management perspective, cash flow has become the critical management index. The establishment of a production system that addresses these considerations is essential for manufacturing industries.

While the need for high-mix low-volume production is clear, there are problems in realizing such production (Nishida, 2000). They include

1) Problems in production management

A reduced order delivery period to customers is essential because the number of rushed orders, additional orders, and orders modified with respect to delivery date and number of products is increasing. The rate of non-repeated order production has also become higher. To realize efficient production, skills in production planning and management are required.

2) Problems in purchasing and supply
The price of each product unit typically increases when the product lot size is small, which increases the time needed for assembly parts preparation and delivery date negotiation because the frequency of these preparations and negotiations also increases. In addition, making precision demand forecasts, securing multiple suppliers, and reinforcing relationships with existing suppliers is required because of the increasing frequency of unexpected assembly parts preparation. As the risk rises of having greater volumes of assembly parts as dead stock, effective production management is required.

3) Problems in production

Facilities’ operation rates become lower as the new production style does not easily lend itself to a flow-type production with conveyors. Therefore, systematically maintaining resources, such as workers and facilities, becomes hard. When one production system must be constructed to manufacture one type of product, a large production space is required in addition to efficient setting up processes and multi-skilled workers.

To solve these problems, Nakatsuka et al. proposed a demand-synchronized production as a type of make-to-order production (Nakatsuka, et al., 2006). There are three characteristics of demand-synchronized production. First, it has the capability for minimum production according to demand levels. Second, demand-synchronized production does not maintain stock for products, parts, or work in process. Third, demand-synchronized production makes products with on-time delivery.

To realize demand-synchronized production, we identify three requirements.

Requirement 1 (R1)
A system must be established to directly transmit order information from customers to factories.

Requirement 2 (R2)
A system must be established to prepare necessary parts without running out of stock.

Requirement 3 (R3)
The production systems must be flexible and capable of producing a variety of products while maintaining high rates of efficiency.

To fulfill these three requirements of demand-synchronized production, two challenges arise. The first, with regard to R3, is the need to develop and construct production systems and facilities characterized by flexibility. With demand-synchronized production, each production system produces a variety of products and executes the setting up processes efficiently. We have previously proposed a module-structured production system to solve this challenge (Tanaka, et al., 2008, 2009). The second challenge, with respect to R1 and R2, is to establish a manufacturing execution system that responds to changing demands and production conditions. The module-structured production system we previously proposed also solves this second challenge.

However a lead time of several days is still necessary to construct the necessary production conditions even when using the module-structured production system. With demand-synchronized production, when constructing flexible production systems to efficiently produce a variety of products, preparation lead time is required to address such physical constraints as making setup changes and supplying the facilities. This preparation lead time must also allow time to arrange suitable software conditions. If forecasts of the required production volumes can be made several days in advance with a certain degree of precision, systematic preparations to construct the production system become possible. If forecasts of demand fluctuations cannot be made with a certain degree of accuracy, there will be a high probability of full production shortages, and the module-structured production system cannot completely realize demand-synchronized production. Moreover, to achieve a condition in which necessary parts are prepared without running out of stock, suppliers must be given precise production forecasts with suitable timing. Therefore, a production forecast method that can provide precise demand forecasts must be developed if demand-synchronized production is to be realized. In this paper, we propose such a production forecast method.
2. Demand Forecast

Manufacturing industries generate production planning and sales campaigns based on short-term demand forecasts. However, these manufacturing industries must make investment plans for facilities and employment for the long- and mid-term.

Many demand forecast methods, such as the moving average forecast and the exponential smoothing forecast, have been proposed (Asada, et al., 2005). The moving average forecast estimates a single model parameter at a time from an average of the last observations, where the last observations represent the moving-average interval. The exponential smoothing forecast estimates a single model parameter at a time using the last observation data and forecast data.

Demand forecast methods usually rely on past demand trend data. Each of these methods consists of three fundamental sub-methods. The first sub-method creates demand forecast information by classifying demand data into three components: a noise component, a trend component, and a cyclical fluctuation component. The second sub-method creates demand forecast information by stretching the trend and cyclical fluctuation components data. The third sub-method creates demand forecast information by stretching and subsequently merging the trend and cyclical fluctuation components data.

The noise component is an irregular fluctuation caused by unexpected demands. The trend component is a fluctuation that includes both increased and decreased fluctuations over long time periods. The cyclical fluctuation component is a regular cycle fluctuation that includes both increased and decreased fluctuations.

The characteristics of demand forecast methods depend on the types of the fluctuation components. The simple moving average method and the first-order exponentially smoothed moving average method use the noise component. The second-order exponentially smoothed moving average method uses the noise component and the trend component. The Winters exponential smoothing model method uses the trend component and the cyclical fluctuation component.

Demand forecast methods that use the noise component must use a large amount of sampling data to get precise forecast results. In demand forecast methods that use the trend component, forecasting demand fluctuations which have extreme changes is difficult. Demand forecast methods that use the cyclical fluctuation component must use sampling data over a long period of time. Therefore, to use current demand forecast methods effectively, the following two conditions must be met:

1) a demand pattern that is relatively stable, and
2) data sampling over a relatively long period of time.

This research aims to precisely forecast the peak-to-valleys in a demand fluctuation for products with unstable order patterns under demand-synchronized production and to consequently forecast the required production volume. Using current methods, precisely forecasting the peak-to-valleys in a demand fluctuation for products with unstable order patterns is difficult. The proposed method for forecasting production volumes uses the analysis results of past order data and determines their similarity through Fourier analysis.

3. Proposed Production Forecast
3.1 Forecast of Production Volume

With demand-synchronized production, when flexible production systems are constructed to produce a variety of products with high efficiency, a preparation lead time is required to manage the physical constraints of making setup changes and supplying facilities, as stated earlier. This preparation lead time also allows for time to arrange suitable software conditions. If forecasts of the required production volumes can be made several days in advance with a certain degree of precision, making systematic preparations for constructing the production system becomes possible.

Our research objectives are to precisely forecast demand fluctuation over several days, thus forecasting the required production volume. In this section, we propose a method for forecasting production volumes with a certain degree of precision several days in advance, based on the analysis results of past order data and a determination of their similarity by Fourier analysis.

Figure 1(a) shows a typical flow of production using current demand forecast methods. Figure 1(b) shows a flow of production using the proposed production forecast methods.

With the typical flow of production, demand information is forecasted using the demand trends information for
products and unofficial information. Production plans are then created based on the demand forecast information results. The component procurement and production preparation activities are concurrently activated based on the production plans. Finally, when order information is received from customers, products are made according to the production plans.

In the flow of production using our proposed production forecast method, production volumes are forecasted using the analysis results of past order data, and their similarity is determined through Fourier analysis. The component procurement and production preparation activities are activated beforehand. When order information is received from customers, products are made.

![Fig. 1 Typical (a) and proposed (b) production flow](image)

3.2 Proposed Method to Forecast Production Volume

We propose a method for forecasting the production volume using past order volumes for one product per day. This method forecasts future production volume while considering information gained by sequentially accumulating past order volumes for one product per day. The procedure followed in the proposed method is as follows:

Step 1: Quote from past order data
Step 2: Create a mathematical expression
Step 3: Forecast future production volume.

Detailed algorithms for each step are as follows.

1) Quote from past order data

Table 1 shows the cumulative orders received for one product based on the relationship between the delivery date and the order receiving date. According to Table 1, for an order that is delivered on January 17, the number of orders 9 days before the delivery date is 3, 5 days before the delivery date is 5, 4 days before the delivery date is 42, 3 days before the delivery date is 49, and 2 days before the delivery date is 60; the total number of orders is 77. For an order that is delivered on January 26, the number of orders 9 days before the delivery date is 41, 5 days before the delivery date is 43, 4 days before the delivery date is 48, and 2 days before the delivery date is 55; the total number of orders is 94.
Table 1 Cumulative orders received based on the relationship between the delivery date and the order receiving date

| Order Receiving Date | Delivery Date | Average Number of Receiving Order |
|----------------------|---------------|-----------------------------------|
|                      | 1/17          | 1/19                              |
| 9-days before        | 3 0 2 1 10 41| 7                                 |
| 8-days before        | 3 4 2 3 10 43| 9                                 |
| 7-days before        | 3 4 2 11 10 43| 10                               |
| 6-days before        | 3 4 2 11 10 43| 10                               |
| 5-days before        | 5 14 3 24 11| 10                                |
| 4-days before        | 42 14 14 10 38| 48                                |
| 3-days before        | 49 34 16 28 41| 48                                |
| 2-days before        | 60 54 20 30 42| 55                                |
| 1-day before         | 77 136 65 61 13| 103                               |

2) Creating a mathematical expression

The average number of each order a number of days before the delivery date is calculated and formulated. The right-most column in Table 1 lists the average number of orders for a given number of days before the delivery date. Figure 2 shows the relationship between the order numbers for a given number of days before the delivery date and the days remaining before the delivery date. Figure 2 presents four orders that are delivered on January 17, 19, 21, and 25. As shown in the graphs, the trends increase for order numbers 4 days and 1 day before the delivery date.

![Graph of order numbers based on a relationship between the delivery date and order receiving date](image)

Fig. 2 Graphs of order numbers based on a relationship between the delivery date and order receiving date

The average number of each order for a given number of days before the delivery date is calculated and formulated by Fourier analysis. The Fourier analysis formula is as follows:
\[ y = \frac{A_0}{2} + \sum_{n=1}^{\infty} (A_n \cos nx + B_n \sin nx) \]  

where

- \( x \) is a real variable
- \( y \) is an outputted real variable,
- \( A_0 \) is a Fourier coefficient,
- \( A_n \) is a Fourier coefficient, and
- \( B_n \) is a Fourier coefficient.

Next, the Fourier coefficients \( A_0, A_n, \) and \( B_n \) \((n = 1, 2, ..., m)\) must be defined. When for an interval \([a, b]\), the data number \((2m+1)\), an approximation formula \(f(x)\) may be obtained by determining the Fourier coefficients \(A_0, A_n, \) and \(B_n \) \((n = 1, 2, ..., m)\) for each data. The real variable \( x \) is defined as the period remaining before the delivery date. The inputted variable \( a \) is defined as the earliest date the order is received for the earliest delivery date. The inputted variable \( b \) is defined as the latest delivery date. The Fourier analysis formula for the interval \([a, b]\) is as follows:

\[ f(x) = \frac{A_0}{2} + \sum_{n=1}^{m} (A_n \cos \frac{2\pi nx}{b-a} + B_n \sin \frac{2\pi nx}{b-a}) \]  

where

- \( f(x) \) is an approximation formula,
- \( x \) is the period remaining before the delivery date,
- \( a \) is a relative origin point for the earliest date the order is received for the earliest delivery date,
- \( b \) is a relative point for the latest delivery date,
- \( A_0 \) is a Fourier coefficient,
- \( A_n \) is a Fourier coefficient, and
- \( B_n \) is a Fourier coefficient.

If we define \( p \) as the number of orders \( c \) days before the delivery date, and \( q \) as the average number of orders \( c \) days before the delivery date, a formula \( G(x) \) for the forecast value is as follows:

\[ G(x) = \frac{p}{q} \times f(x) \]  

where

- \( G(x) \) is a forecast value,
- \( f(x) \) is an approximation formula that is defined in Equation 2,
- \( p \) is the number of orders \( c \) days before the delivery date, and
- \( q \) is the average number of orders \( c \) days before the delivery date.

As shown in Figure 2, based on the average number of orders for a given number of days before the delivery date, \( a \) is 0 which means the relative origin point for the earliest date the order is received for the earliest delivery date as January 8, nine days before January 17. And \( b \) is 16 which means the relative point for the latest delivery date as January 25, one day before January 26. The interval \([0, 16]\) equals 16, since \((2m+1)\) equals \((16−1)\), whereby one day (first day) is subtracted from the interval. \( m \) equals 7. Thus, we formulated \( f(x) \) as follows:
\[ f(x) = (43.45/2) + 18.72234717\cos((2 \pi /16)x) \]
\[ - 13.07189302\sin((2 \pi /16)x) \]
\[ + 7.454082066\cos((4 \pi /16)x) \]
\[ - 13.0425641\sin((4 \pi /16)x) \]
\[ + 5.595168132\cos((6 \pi /16)x) \]
\[ - 10.18474492\sin((6 \pi /16)x) \]
\[ + 6.8\cos((8 \pi /16)x) \]
\[ - 8.8725\sin((8 \pi /16)x) \]
\[ + 4.096774876\cos((10 \pi /16)x) \]
\[ - 8.44854775\sin((10 \pi /16)x) \]
\[ + 0.870917934\cos((12 \pi /16)x) \]
\[ - 4.822526413\sin((12 \pi /16)x) \]
\[ - 0.064290175\cos((14 \pi /16)x) \]
\[ - 1.535695879\sin((14 \pi /16)x) \]

(4)

3) Forecasting future production volume

Future production volume is forecasted using the formulated \( f(x) \). For example, when we forecast production volume 3 days before the delivery date, we calculate the total number of orders 3 days before the delivery date. Next, we compare the total number and the average number of orders 3 days before the delivery date and calculate a coefficient that lies somewhere between the total number and the average number. The future production volume is calculated by multiplying the calculated coefficient and the total number of orders for a given delivery day.

3.3 Evaluation of the Results

There are four factors to evaluate in determining the future production volume. We define the number of sampling data as a parameter \( X \) and a forecast error value as a parameter \( d \).

1) The absolute average error (\( A_a \)) is formulated as follows:

\[ A_a = \frac{\sum|d|}{X} \]  

where

\( A_a \) is the absolute average error,
\( X \) is the number of sampling data, and
\( d \) is the forecast error value.

2) The root mean square average (\( A_c \)) is formulated as follows:

\[ A_c = \frac{\sum d^2}{X} \]  

where

\( A_c \) is the root mean square average,
\( X \) is the number of sampling data, and
\( d \) is the forecast error value.

3) The peak-to-valley match rate (\( E_v \)) is formulated as follows:

\[ E_v = \frac{A_v}{X} \times 100 \]
where
\( E_v \) is the peak-to-valley match rate,
\( X \) is the number of sampling data, and
\( X_e \) is the number of peak-to-valley matches.

4) The relative error average (Re) is formulated as follows:

\[
Re = \frac{\sum|\hat{y}_i - y_i|}{X} \times 100
\]

where
\( R_e \) is the relative error average,
\( X \) is the number of sampling data,
\( d \) is the forecast error value, and
\( y \) is the forecast value.

4. Experiment to Forecast Production Volume

4.1 Experiment Data

In this section, we describe the experiments conducted using the proposed production forecast method and the actual order data, which can be characterized as follows (Shimoda, et al., 2008).

1) The actual order data period is from January 17 to March 4, excluding Saturdays and Sundays.
2) The actual order data products are classified into fourteen types, based on their order pattern similarities. The fourteen product classifications are each defined as a product group (A–N).
3) The actual order data for each product group forecasts numbers of orders based on the relationship between the delivery date and the order receiving date.

4.2 Experiment

In this experiment, we forecasted future production volumes based on sequentially accumulated information on the past order volumes for the fourteen product types per day. In this section, we focus on two product groups, D and M, which have different characteristics. Table 2 shows the number of orders for product groups D and M, based on the relationship between the delivery date and the order receiving date. Results of the forecasted production volume are evaluated based on \( Aa, Ac, Ev, \) and \( Re \).
Table 2 Actual order data for product groups D and M

| Delivery Date | Product D | Product M | Delivery Date | Product D | Product M |
|---------------|-----------|-----------|---------------|-----------|-----------|
| 1/17          | 422       | 49        | 1/9           | 864       | 28        |
| 1/18          | 492       | 0         | 2/10          | 2,771     | 5         |
| 1/19          | 825       | 0         | 2/14          | 1,444     | 1         |
| 1/20          | 854       | 0         | 2/15          | 1,201     | 26        |
| 1/21          | 1,160     | 101       | 2/16          | 830       | 2,012     |
| 1/24          | 875       | 1,002     | 2/17          | 1,326     | 70        |
| 1/25          | 493       | 14        | 2/18          | 1,834     | 110       |
| 1/26          | 937       | 123       | 2/21          | 1,978     | 40        |
| 1/27          | 916       | 102       | 2/22          | 1,293     | 52        |
| 1/28          | 2,150     | 33        | 2/23          | 670       | 68        |
| 1/31          | 908       | 3         | 2/24          | 1,626     | 0         |
| 2/1           | 1,226     | 2,170     | 2/25          | 1,976     | 262       |
| 2/2           | 1,272     | 143       | 2/28          | 1,920     | 0         |
| 2/3           | 1,554     | 2         | 3/1           | 1,540     | 4,000     |
| 2/4           | 2,441     | 5         | 3/2           | 830       | 1         |
| 2/7           | 1,729     | 10        | 3/3           | 1,988     | 14        |
| 2/8           | 1,357     | 77        | 3/4           | 1,769     | 0         |

4.3 Experiment Results

1) Product group D

We forecasted two types of production volumes for the delivery date in the period January 17–March 3. The first forecasted production volume was generated by the orders received 7 days before the delivery date. The second forecasted production volume was generated by the orders received 3 days before the delivery date. We compared these two forecasted production volumes with the actual order data.

Table 3 and Figure 3 show relationships between the number of product group D’s orders at a given number of days before the delivery date and the days remaining before the delivery date between February 23 and March 3. As shown in the graphs, the trends for the number of orders 14 days and 8 days before the delivery date are large. We also see that the trends for the number of orders from 7 days to 1 day before the delivery date are stable. Based on the average number of orders for a given number of days before the delivery date, a is 0 which means the relative origin point for the earliest date the order is received for the earliest delivery date as January 9, nine days before January 17. And b is 42 which means the relative point for the latest delivery date as March 3, one day before March 4. The interval [0, 42] equals 42. (2m+1) equals (42−1), whereby one day (first day) is subtracted from the interval. m equals 20. We formulated $G(x)$ by Fourier analysis as follows:

$$G(x) = \langle p(x) \rangle \{ 766.91563032 + 196.1962087\cos[(2 \pi / 42)x] + 358.6058725\sin[(2 \pi / 42)x] + 30.4387286\cos[(4 \pi / 42)x] - 195.7620993\sin[(4 \pi / 42)x] + 18.13413698\cos[(6 \pi / 42)x] + 138.2157109\sin[(6 \pi / 42)x] + 19.19772456\cos[(8 \pi / 42)x] + 74.60654338\sin[(8 \pi / 42)x] + 15.94993808\cos[(10 \pi / 42)x] - 31.48489801\sin[(10 \pi / 42)x] + 1.20128302\cos[(12 \pi / 42)x] + 101.160118\sin[(12 \pi / 42)x] + 5.444408\cos[(14 \pi / 42)x] + 31.48489801\sin[(14 \pi / 42)x] + 25.70705395\cos[(16 \pi / 42)x] - 60.3594395\sin[(16 \pi / 42)x] + 24.34588513\cos[(18 \pi / 42)x] - 5.607966408\sin[(18 \pi / 42)x] + 17.1150038\cos[(20 \pi / 42)x] - 31.48489801\sin[(20 \pi / 42)x] + 19.19772456\cos[(22 \pi / 42)x] - 31.48489801\sin[(22 \pi / 42)x] + 19.19772456\cos[(24 \pi / 42)x] - 31.48489801\sin[(24 \pi / 42)x] + 17.1150038\cos[(26 \pi / 42)x] - 31.48489801\sin[(26 \pi / 42)x] + 17.1150038\cos[(28 \pi / 42)x] - 31.48489801\sin[(28 \pi / 42)x] + 17.1150038\cos[(30 \pi / 42)x] - 31.48489801\sin[(30 \pi / 42)x] + 17.1150038\cos[(32 \pi / 42)x] - 31.48489801\sin[(32 \pi / 42)x] + 17.1150038\cos[(34 \pi / 42)x] - 31.48489801\sin[(34 \pi / 42)x] + 17.1150038\cos[(36 \pi / 42)x] - 31.48489801\sin[(36 \pi / 42)x] + 17.1150038\cos[(38 \pi / 42)x] - 31.48489801\sin[(38 \pi / 42)x] + 17.1150038\cos[(40 \pi / 42)x] - 31.48489801\sin[(40 \pi / 42)x] + 17.1150038\cos[(42 \pi / 42)x] - 31.48489801\sin[(42 \pi / 42)x] \}.$$
\[ p \text{ is the number of orders } c \text{ days before the delivery date and } q \text{ is the average number of orders } c \text{ days before the delivery date. } x \text{ equals 41.} \]

Table 3 Actual order data for product group D based on the relationship between the delivery date and the order receiving date

| Order Receiving Date | 23-Feb | 24-Feb | 25-Feb | 26-Feb | 1-Mar | 2-Mar | 3-Mar | 4-Mar | Average |
|----------------------|--------|--------|--------|--------|-------|-------|-------|-------|---------|
| 15                   | 55     | 164    | 583    | 429    | 309   | 475   | 343   | 1,040 | 348     |
| 14                   | 155    | 349    | 585    | 525    | 463   | 490   | 366   | 1,491 | 510     |
| 13                   | 175    | 355    | 1,060  | 635    | 478   | 535   | 1,298 | 1,500 | 565     |
| 12                   | 200    | 362    | 1,060  | 685    | 480   | 609   | 1,300 | 1,521 | 561     |
| 11                   | 210    | 364    | 1,062  | 688    | 505   | 611   | 1,305 | 1,522 | 562     |
| 10                   | 224    | 369    | 1,067  | 758    | 511   | 611   | 1,308 | 1,522 | 573     |
| 9                    | 354    | 460    | 1,164  | 808    | 707   | 673   | 1,866 | 1,660 | 743     |
| 8                    | 390    | 1,183  | 1,183  | 815    | 824   | 694   | 1,668 | 1,665 | 822     |
| 7                    | 429    | 1,216  | 1,205  | 1,460  | 940   | 706   | 1,898 | 1,869 | 887     |
| 6                    | 431    | 1,218  | 1,508  | 1,513  | 866   | 715   | 1,913 | 1,689 | 896     |
| 5                    | 437    | 1,227  | 1,516  | 1,552  | 908   | 745   | 1,921 | 1,745 | 941     |
| 4                    | 464    | 1,266  | 1,555  | 1,631  | 1,002 | 760   | 1,962 | 1,769 | 999     |
| 3                    | 482    | 1,350  | 1,606  | 1,643  | 1,041 | 776   | 1,988 | 1,769 | 1,036   |
| 2                    | 503    | 1,396  | 1,627  | 1,692  | 1,212 | 830   | 1,988 | 1,769 | 1,096   |
| 1                    | 670    | 1,626  | 1,976  | 1,920  | 1,540 | 830   | 1,988 | 1,769 | 1,337   |

Fig. 3 Number of product group D's orders based on the relationship between the delivery date and the date the orders were received
Results of the forecasted production volume 7 days and 3 days before the delivery date using Formula 9 are listed in Figure 4 and Table 4. For the forecasted production volume 7 days before the delivery date, the result for $E_v$ is approximately 85%. We therefore confirmed that our proposed method could precisely forecast peak-to-valleys even when the delivery date was 7 days away. The evaluation item $A_a$ nearly equals 300. This parameter value is larger than that 3 days before the delivery date. The evaluation item $R_e$ is approximately 25%. These results mean that while our proposed method could precisely forecast the peak-to-valley, the production volume error value was larger. However, for the forecasted production volume 3 days before the delivery date, the result for $E_v$ is approximately 80%, the result for $A_a$ is approximately 180, and the result for $R_e$ is approximately 15%. These results mean that our proposed method could precisely forecast the peak-to-valley and the production volume. The precision of the results rises as the day of delivery approaches. We confirmed that our proposed method could precisely forecast the peak-to-valleys and the production volume.

2) Product group M

For product group M, we forecasted two production volume types for the delivery date period between January 17 and March 3. The first forecasted production volume was generated for orders received 7 days before the delivery date. The second forecasted production volume was generated for orders received 3 days before the delivery date. We compared these two forecasted production volumes with the actual order data.

Table 5 and Figure 5 show the relationships between the number of product group M’s orders for a given number of days before the delivery date and the days remaining before the delivery date from February 23 to March 3. As shown in the graphs, there are great differences in the trends between cases with a large number of orders received and those that received no orders. There is a trend showing an irregularly large volume of orders several days before the delivery date. Based on the average number of orders for a given number of days remaining before the delivery date, a is 0 which means the relative origin point for the earliest date the order is received for the earliest delivery date as January 9, which is nine days before January 17. And b is 42 which means the relative point for the latest delivery date as March 3,
which is one day before March 4. The interval [0, 42] equals 42. (2m+1) equals (42−1), whereby one day (first day) is subtracted from the interval. m equals 20. We formulated G(x) by Fourier analysis as follows:

\[
G(x) = \left( \frac{p}{q} \right) \left[ 252.7535701 \cdot \cos\left( \frac{2\pi}{42} x \right) - 158.5259167 \cdot \sin\left( \frac{2\pi}{42} x \right) - 15.6561506 \cdot \cos\left( \frac{4\pi}{42} x \right) - 33.19195475 \cdot \sin\left( \frac{4\pi}{42} x \right) - 4.82463378 \cdot \sin\left( \frac{6\pi}{42} x \right) - 158.5259167 \cdot \sin\left( \frac{6\pi}{42} x \right) - 15.6561506 \cdot \sin\left( \frac{8\pi}{42} x \right) - 33.19195475 \cdot \cos\left( \frac{8\pi}{42} x \right) + 9.662724781 \cdot \cos\left( \frac{10\pi}{42} x \right) - 25.01219916 \cdot \sin\left( \frac{10\pi}{42} x \right) - 7.225798921 \cdot \cos\left( \frac{12\pi}{42} x \right) - 16.38455551 \cdot \sin\left( \frac{12\pi}{42} x \right) - 1.245419949 \cdot \cos\left( \frac{14\pi}{42} x \right) + 14.04445285 \cdot \sin\left( \frac{14\pi}{42} x \right) - 1.43871018 \cdot \cos\left( \frac{16\pi}{42} x \right) + 4.600491245 \cdot \sin\left( \frac{16\pi}{42} x \right) + 4.84382374 \cdot \cos\left( \frac{18\pi}{42} x \right) - 15.77340576 \cdot \sin\left( \frac{18\pi}{42} x \right) - 8.89510163 \cdot \cos\left( \frac{20\pi}{42} x \right) + 6.113820132 \cdot \sin\left( \frac{20\pi}{42} x \right) + 4.203245568 \cdot \cos\left( \frac{22\pi}{42} x \right) - 5.494181517 \cdot \sin\left( \frac{22\pi}{42} x \right) - 4.819788612 \cdot \cos\left( \frac{24\pi}{42} x \right) + 6.723915607 \cdot \sin\left( \frac{24\pi}{42} x \right) + 3.580028536 \cdot \cos\left( \frac{26\pi}{42} x \right) - 5.023810029 \cdot \sin\left( \frac{26\pi}{42} x \right) + 4.777851333 \cdot \cos\left( \frac{28\pi}{42} x \right) - 7.24356878 \cdot \sin\left( \frac{28\pi}{42} x \right) - 0.826129482 \cdot \cos\left( \frac{30\pi}{42} x \right) + 0.424466369 \cdot \sin\left( \frac{30\pi}{42} x \right) + 0.205584443 \cdot \cos\left( \frac{32\pi}{42} x \right) - 3.114543474 \cdot \sin\left( \frac{32\pi}{42} x \right) + 2.429415471 \cdot \cos\left( \frac{34\pi}{42} x \right) - 3.568529196 \cdot \sin\left( \frac{34\pi}{42} x \right) - 1.878311683 \cdot \cos\left( \frac{36\pi}{42} x \right) + 0.047162584 \cdot \sin\left( \frac{36\pi}{42} x \right) + 0.017479351 \cdot \cos\left( \frac{38\pi}{42} x \right) - 1.861841645 \cdot \sin\left( \frac{38\pi}{42} x \right) + 2.73629862 \cdot \cos\left( \frac{40\pi}{42} x \right) - 0.456482592 \cdot \sin\left( \frac{40\pi}{42} x \right) \right] 
\]

\[p\] is the number of orders \(c\) days before the delivery date, and \(q\) is the average number of orders \(c\) days before the delivery date. \(x\) equals 41.

Figure 6 and Table 6 show the forecasted production volume results, using Formula 10, 7 days and 3 days before the delivery date. For the forecasted production volume 7 days and 3 days before the delivery date, the \(Ev\) result is approximately 90%. The evaluation item \(Aa\) is small. The evaluation item \(Re\) is approximately 90 because \(Re\) is reflected by the trend in which there are the great differences between the case with a large number of orders received and the one that received no orders. The precision of the results rises as the delivery day approaches. These results confirm that our proposed method could precisely forecast the peak-to-valleys even when the delivery date is 7 days and 3 days away. We also confirmed that our proposed method could forecast the production volume with a certain degree of precision.
Table 5 Actual order data for product group M based on the relationship between the delivery date and the order receiving date

| Order Receiving Date | Delivery Date | Average |
|----------------------|---------------|---------|
|                      | 23-Feb        |        |
|                      | 24-Feb        |        |
|                      | 25-Feb        |        |
|                      | 28-Feb        |        |
|                      | 1-Mar         |        |
|                      | 2-Mar         |        |
|                      | 3-Mar         |        |
|                      | 4-Mar         |        |
| 30 60 0 140 0 0 0 0 0 0 15 |   |   |
| 29 60 0 140 0 0 0 0 0 0 14 |   |   |
| 28 60 0 140 0 0 0 0 0 0 13 |   |   |
| 27 60 0 140 0 0 0 0 0 0 15 |   |   |
| 26 60 0 140 0 0 0 0 0 0 14 |   |   |
| 25 60 0 140 0 0 0 0 0 0 14 |   |   |
| 24 60 0 140 0 0 0 0 0 0 13 |   |   |
| 23 60 0 140 0 0 0 0 0 0 15 |   |   |
| 22 60 0 140 0 0 0 0 0 0 15 |   |   |
| 21 60 0 140 0 0 0 0 0 0 14 |   |   |
| 20 60 0 140 0 2,000 0 12 0 106 |   |   |
| 19 60 0 140 0 4,000 0 12 0 184 |   |   |
| 18 60 0 240 0 4,000 0 12 0 181 |   |   |
| 17 60 0 240 0 4,000 0 12 0 175 |   |   |
| 16 60 0 240 0 4,000 0 12 0 243 |   |   |
| 15 60 0 240 0 4,000 0 12 0 234 |   |   |
| 14 60 0 240 0 4,000 0 14 0 226 |   |   |
| 13 60 0 240 0 4,000 0 14 0 220 |   |   |
| 12 60 0 240 0 4,000 0 14 0 213 |   |   |
| 11 60 0 240 0 4,000 0 14 0 272 |   |   |
| 10 60 0 240 0 4,000 0 14 0 297 |   |   |
| 9 60 0 240 0 4,000 0 14 0 290 |   |   |
| 8 60 0 240 0 4,000 0 14 0 290 |   |   |
| 7 60 0 240 0 4,000 0 14 0 291 |   |   |
| 6 60 0 240 0 4,000 0 14 0 291 |   |   |
| 5 60 0 240 0 4,000 0 14 0 291 |   |   |
| 4 60 0 240 0 4,000 0 14 0 296 |   |   |
| 3 60 0 240 0 4,000 0 14 0 300 |   |   |
| 2 60 0 240 0 4,000 0 14 0 301 |   |   |
| 1 60 0 240 0 4,000 0 14 0 310 |   |   |

Fig. 5 Number of product group M’s orders based on the relationship between the delivery date and the order receiving date.
5. Conclusion

In demand-synchronized production, when constructing flexible production systems to produce a variety of products with high efficiency, a preparation lead time is required due to such physical constraints as making setup changes and supplying the facilities. The preparation lead time must also allow for time to arrange suitable software conditions. If it is possible to forecast required production volumes several days in advance with a certain degree of precision, then it is possible to make systematic preparations for the construction of the production system.

Our objectives in conducting this research were to precisely forecast demand fluctuation over a period of several days in order to forecast production volume. We proposed a method for forecasting production volumes based on the analysis results from past order data and determining their similarity through Fourier analysis. We conducted experiments with actual order data using our proposed method for forecasting production volume to confirm the efficiency of our proposed method. We confirmed that our proposed method could precisely forecast the peak-to-valleys of the demand fluctuation as well as the production volume with a certain degree of precision. Since forecasting required production volumes several days in advance with a certain degree of precision is possible, making systematic preparations for constructing a production system using demand-synchronized production also becomes possible.

In future research, we plan to improve production forecast accuracy and apply our proposed method to actual production systems.

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