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SPECIAL ISSUE

Methods of Construction and Features of Work Schedules for Mechanical Engineering Enterprises

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Abstract—This paper considers the challenges and methods of constructing work schedules at mechanical engineering enterprises that manufacture large quantities of products and components for their assembly. The concepts and principles of information aggregation create the development basis of these methods. The considered methods make it possible to create coordinated work schedules for all production divisions of mechanical engineering enterprises. Such schedules make it possible to define the start and end times of processing for each components batch on all enterprise equipment.

Keywords: work schedules, work schedule construction methods, modeling methods, processing equipment, components, product assembly, manufacturing technology, production divisions, aggregation principles

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1. INTRODUCTION

Tasks of scheduling theory typically arise when it is possible to choose one or another sequence for performing works [1–3]. The results of their solutions are highly effective and noticeable in industry. The creation and using work schedules created for production systems and production divisions allows for significant reductions in the time required to complete incoming orders without the need for additional investment.

A fairly large number of effective methods exist for constructing such work schedules [1–3]. Unfortunately, these methods turned out to be unsuitable for building work schedules in enterprises with a large number of equipment and the production of significant volumes of products. The unsuitability of these methods is due to the extremely large sizes of the schedules at these enterprises. However, it is precisely for such enterprises that it is possible to obtain the greatest economic benefit from the use of work schedules.

Enterprise efficiency significantly increases when using schedules created for manufacturing of incoming orders on all equipment within the enterprise. Such schedules, referred in [5] to as coordinated, ensure the manufacturing technology for each batch of components on all equipment at the enterprise. Furthermore, such schedules must avoid unforced equipment downtime, and, where possible, minimize forced equipment downtime.

Paper [4] proposes an approach using aggregation principles to create coordinated schedules in enterprises. Papers [5, 6] applied this approach to form work schedules in engineering enterprises with slipway and conveyor assembly of manufactured products. However, in cases where it is necessary to create schedules for processing a large number of components at enterprises with a significant amount of equipment, major problems arise. The methods proposed in [4] and developed in [5, 6] for constructing work schedules in such cases may prove insufficiently effective, and in some cases, completely unsuitable.

This paper proposes methods for constructing work schedules at such mechanical engineering enterprises. The proposed methods for constructing work schedules utilize the ideas and principles of sequential aggregation.

2. PROBLEM STATEMENT

Let us consider the formulation of the problem of manufacturing components in the production divisions of enterprises for the assembly of manufactured products from them.

Let us say that an enterprise has M production divisions. These divisions manufacture components for assembly L types of manufactured products. The enterprise manufactures products in batches, the sizes of which are N_l $(l = 1, \dots, L)$.

The quantity and types of components, assemblies, and parts are known for each manufactured product. Furthermore, the production time and sequence of each batch of components for any type of manufactured product are known, as are the changeover times for the equipment required for their production. The enterprise manufactures products assembled from components, and units manufactured within the enterprise's production divisions, as well as from components purchased from third-party manufacturers.

The task requires the creation for enterprise such work schedule, in which any component it is necessary to manufacture in accordance with its technological route. Furthermore, it is desirable to complete the incoming order according to this schedule in the shortest possible time.

3. PRINCIPLES OF CONSTRUCTING SCHEDULES FOR PROCESSING COMPONENTS AT ENTERPRISES

Let us consider the principles and specifics of developing schedules for the production of components at mechanical engineering enterprises.

At discrete-production enterprises, it is advisable to create work schedules for all equipment within the enterprise. Only such work schedules will ensure the execution of component manufacturing technology at the enterprise and can reduce the lead-time for incoming orders.

As already noted, it is impossible to create work schedules at enterprises using existing methods, since the work schedule sizes, even at small enterprises, are too large for these methods.

In [4], the author proposed an approach to developing methods suitable for scheduling at mechanical engineering enterprises. The idea of such approach, which utilizes information aggregation principles, is to form special groups of components. Along with these component groups, we form equipment groups for processing of such components.

We note that the formation of equipment groups does not imply changes in the administrative structure of enterprises and necessary only for scheduling work. However, it is convenient to select enterprise production divisions as equipment groups. Each component group includes only those components that, in accordance with their manufacturing technology, necessary to deliver to the same production divisions in the same order.

However, within the enterprise production divisions, components in each group are processed using their own technological routes of processing. We can consider of components groups formed in this way as "generalized parts," and the equipment groups using for their processing as "generalized machines."

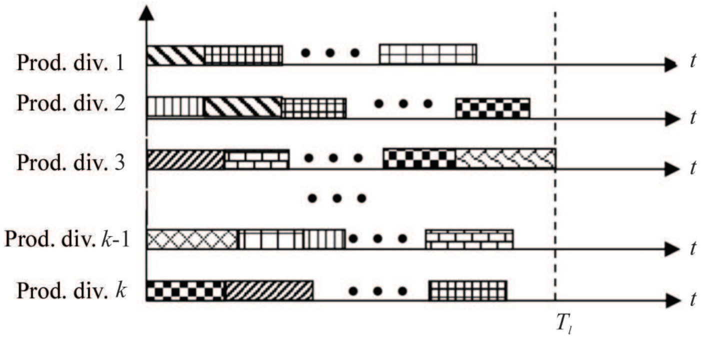

Fig. 1. Gantt chart of the "framework" schedule for processing the formed component groups of the Jth product.

Indeed, groups of components are delivered to the production divisions of enterprises for processing in accordance with their manufacturing technology, just as parts undergoing machining are delivered to the machining equipment.

For each manufactured part, the machining sequence is known on the equipment of the production division its machined. For each group of components, the processing sequence in the enterprise divisions is also known, according to the principles for forming such groups. For each manufactured part, the processing times are known or normative of its processing times are set for all equipment used. The processing time for a group of components in any division that processes we can to determine by creating a processing schedule of such group in that division. The processing time for a group of components in a division is the completion time of processing the last component of that group on the division's equipment.

It should be noted that in the future we will use the schedules for processing groups of components in divisions to generate schedules for the production of components at enterprises.

In [4], the author called the production schedule for groups of components in the enterprise's divisions a "framework" schedule.

The dimensionality of such a schedule is significantly smaller than that of the original schedule. This is because in the "framework" schedule, instead of several dozen pieces of equipment in each division, only one unit is considered—a "generalized machine" or enterprise division. Instead of several dozen pieces of components, only one unit is considered—a "generalized part" or group of components.

Therefore, such a schedule it is possible to construct using traditional scheduling methods if, after aggregation, the dimensionality of the problem of constructing a "framework" schedule is not too large for these methods.

Parts processing schedules in production systems and areas it is possible to represent using Gantt charts [1–3]. "Wireframe" schedules also it is possible to represent using these charts. Figure 1 shows a Gantt chart representing an example of a "wireframe" schedule for processing component groups for the lth product in an enterprise's production divisions.

The Gantt chart for such a schedule, as shown in Fig. 1, has virtually the same appearance as the Gantt chart for a parts processing schedule in a manufacturing division [1–3]. However, in a "wireframe" Gantt chart, instead of machines, the ordinate axis represents the enterprise's production divisions (production systems and areas, shops). Furthermore, in such a chart, the abscissa axis represents the processing times of groups of parts in the corresponding divisions, instead of the time of processing parts.

In "framework" schedules, just as with batch-based component production, it is possible to reduce forced downtime in production divisions by transferring some of the processed batches from

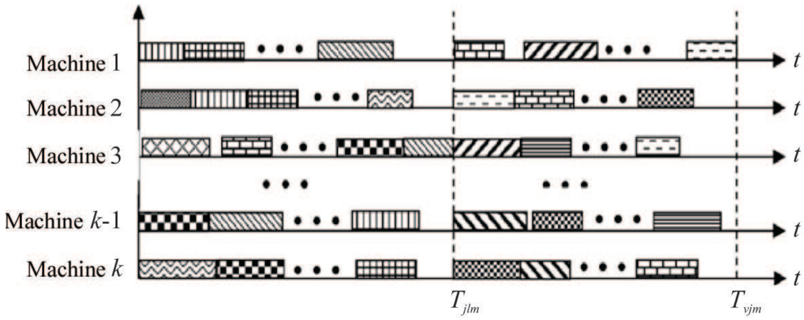

Fig. 2. Gantt chart of the processing of the ith and vth adjacent groups of components of the Jth product in the mth production division.

the processed group to the division next the technological route for processing this components group if if the division is already available.

The resulting "framework" schedule allows for the rapid creation of a preliminary, agreed-upon work schedule for the enterprise. The creation of this schedule, which will be referred to hereafter as an "expanded framework" or "unpacked framework" schedule, is conveniently explained by constructing a Gantt chart for it. A Gantt chart designed for an "expanded framework" or "unpacked framework" schedule has a separate x-axis for each equipment unit in the enterprise. Each axis represents the processing times of components manufactured on the equipment in the division corresponding to this x-axis.

It's worth remembering here that processing schedules for all component groups have already been created for the divisions where these groups are to be processed according to their manufacturing technology, since they determined their processing times for the "framework" schedule.

Therefore, an "expanded framework" or "unpacked framework" schedule is created by placing the previously created processing schedules for component groups in that division in the Gantt chart at the positions of each divisions and on the axes corresponding to the same equipment. The created processing schedules for component groups are placed at the positions of each division in the same order as was obtained when creating the "framework" schedule. The processing schedule for the next component group in each division can be placed on the "expanded framework" schedule diagram only after the processing of the last component from the previous group is completed.

Therefore, the completion times for the "expanded framework" and "framework" schedules will coincide. An "expanded framework" schedule generated using this scheme will be the agreed-upon schedule at the enterprise level. This is true because in this schedule, processing of each component begins on any equipment used by the enterprise only when its processing is completed on the preceding equipment along the manufacturing route for that component.

However, such a work schedule contains many "unforced" equipment downtimes during the processing of adjacent groups of components, making this schedule not entirely successful. This can be seen by plotting a Gantt chart containing a fragment of such a schedule (Fig. 2), which shows the processing schedule for the ith and vth adjacent groups of components of the lth product in the mth division.

Equipment downtime in such schedules arises due to the rules for constructing "framework" schedules. According to these rules, processing of the next group of components in a division can begin only after the last component from the previous group has been processed, and the equipment freed up from processing components from the previous group will remain idle. Therefore, the work duration obtained using such a schedule will be increased due to these downtimes, and using it as a schedule for the entire enterprise, as already noted, is impractical.

Such downtime it is possible to reduce by performing a “schedule gluing” operation. After this operation, equipment freed up from processing components of the current group in each production division is immediately used to process components of the next group, if possible.

As noted, the dimensionality of the “framework” schedule will be significantly smaller than that of the original schedule. Therefore, in many cases, such a schedule, unlike the original schedule, t is possible to construct using existing methods in a reasonable time.

Furthermore, as noted earlier, an “extended framework” schedule it is possible to construct based on a “framework” schedule, which is a coordinated schedule at the enterprise level. After “merging” the “extended framework” schedule, it is possible to convert into a coordinated schedule for the enterprise, defining a sequence that does not disrupt the processing technology of components across all equipment within the enterprise.

Here, we assumed that all the necessary work schedules it is possible to construct, since we were examining the use of aggregation concepts to construct work schedules at mechanical engineering enterprises.

However, in some cases, especially when schedules need to be constructed at enterprises with a large number of production division and equipment within them, as well as those processing a large number of components, significant problems may arise. One of these problems is the excessively large dimensionality of the resulting work schedules, which can lead to an unacceptably long time for scheduling.

4. BUILDING LARGE-SCALE PROCESSING SCHEDULES

Let us consider the principles and specifics of creating large-scale work schedules that arise at enterprises with a large number of production divisions and equipment in them, as well as at enterprises that process a large number of components.

The dimensionality of work schedules at such enterprises, as already noted, are extremely large. Therefore, existing methods turns out to be unsuitable for constructing such work schedules. It is necessary to develop special methods using the ideas and principles of the “framework” schedule construction method described above. These methods provide the ability to perform additional iterations when the dimensionality of the “framework” schedule remains too large. Each of these iterations involves a new aggregation step.

At each aggregation stage, the proposed method selects production divisions from the previous stage, combines them, and forms groups of components for processing in these divisions. It is advisable to combine between two and seven to ten production divisions. The production division formed as a result of combining the production divisions of the previous stage and the groups of components formed for processing in them receive the number of the current stage. We will discuss the formation of component groups in more detail in the next section.

After the formation of divisions, at the new stage of aggregation it is necessary to form groups of components, whose processing must occur in these divisions. Each group of components at the new stage includes groups of components from the previous stage, which, in accordance with the production technology, it is necessary to produce in the same divisions at the new stage.

Therefore, the number of component groups in a new stage cannot exceed the number of component groups in the previous stage. If some component groups in a new stage include even a few component groups from the previous stage, the number of component groups in the new stage will be significantly smaller than the number of component groups in the previous stage. Furthermore, due to the consolidation of production divisions that occurs at each aggregation stage, their number in the new stage will be smaller than in the previous stage.

Therefore, the dimension of the “framework” schedule for processing groups of components in production divisions after the aggregation stage can only be smaller than the dimension of the “framework” schedule before this stage, and in many cases, significantly smaller. During the implementation of the aggregation stages, it is advisable to select as combined production divisions the production divisions of the next-level enterprise that include several production divisions from the previous stage to be combined. For example, for production divisions such as production areas, the next-level production divisions are the production shops containing several production divisions to be combined.

For more clearly and conveniently description of the approach to constructing “framework” schedules of large dimensionality, it is convenient to introduce the following notation. We will call the initially formed production divisions or equipment groups Stage 1 production divisions or equipment groups. The groups of components processed in these production divisions or equipment groups we call Stage 1 component groups.

The production divisions formed in the second aggregation stage will be referred to as Stage 2 production divisions. The groups of components processed in these production divisions will be referred to as Stage 2 component groups. Each Stage 2 component group is formed according to the same rule as a Stage 1 component group. According to this rule, all components in a Stage 2 component group are delivered in the same order for processing to the same Stage 2 production divisions or equipment groups.

By analogy, the production divisions formed at the nth stage of aggregation will be called production divisions of the nth stage, and each group of components formed at the nth stage will be called a component group of the nth stage. Each group of components of the nth stage is formed according to the same rules as the group of components of the 1st, 2nd, and 3rd stages. The production divisions at each aggregation stage, starting with the second, are formed from the production divisions of the previous stage. The component groups at each stage of aggregation, starting with the second, are also formed from the component groups of the previous stage.

The principles of creating and using such methods it is conveniently examined in the following example, where the large dimensionality of the work schedule being constructed at an enterprise leads to insurmountable difficulties.

Furthermore, although schedules for processing component groups in the enterprise’s production divisions can be built using existing methods in an acceptable time, the dimensionality of the “framework” schedule turns out to be too large, and building it using existing methods require an unacceptably long time.

After merging several production divisions and forming groups of components for processing in these divisions, it is advisable to evaluate the possibility of creating a “framework” schedule at the enterprise with using of existed methods. This assessment it is possible to make based on the number of production divisions and component groups, which will be known after their formation.

It should be noted here that a preliminary assessment of the possibility of constructing a “framework” schedule is extremely important and should be used when making decisions about scheduling. Existing scheduling methods allow for the rapid and reliable creation of good work schedules [1–3] when the number of parts and equipment units is not significant. As the number of parts and equipment units increases, the time required to create a work schedule will increase. However, starting from certain values of these quantities, the increase in schedule creation time will be almost exponential. Creating a schedule for large values of these quantities may require an unacceptably long time.

For each scheduling method, the values at which schedule generation time begins to increase sharply will vary. Understanding and estimating the time required to obtain a completed schedule during the scheduling process is very difficult. Therefore, using existing methods without preliminary scheduling feasibility assessments can lead to significant time expenditures, and very often, completing the required schedule within an acceptable timeframe is impossible.

Let us continue our consideration of an example in which schedules can be generated and processing times for all component groups determined in the divisions of the enterprise where they are processed. However, the extremely large dimensionality of the "framework" schedule precludes its construction using existing methods.

In this case, it is advisable to perform the next aggregation stage, which will be the second one. At this stage, the production divisions of the first stage are combined and the production divisions of the second stage are formed. Then, the component groups of the first stage are used to form the component groups of the second stage. The process of forming component groups will be described in more detail in the next section.

After forming the component groups, the feasibility of constructing a "framework" schedule is checked, since the dimensionality of the "framework" schedule after each aggregation stage can only decrease. If the check does not confirm the feasibility of constructing a "framework" schedule, the next aggregation stage is performed. Otherwise, a "framework" schedule is constructed, and after its construction, an "expanded framework" schedule is generated. Based on this schedule, after the "gluing" operation, a schedule is generated that can be used for planning and managing the enterprise's work.

For determination of the processing time of the formed group of components stage 1 in the division of the 1st stage it is possible to build schedule of processing such components group in this division. However, at the stages of aggregation, starting from the second stage, it is proposed to first build "framework" schedules in order to schedule the work of groups of components in the formed divisions. The following circumstances determine the feasibility of constructing a "framework" schedule.

First, existing methods may be unsuitable for constructing schedules for processing components from formed groups in production divisions of a new stage, consisting of many production divisions from the previous stage. With "framework" schedules, it is possible to construct schedules of very large dimensions.

Second, schedules have already been constructed for all groups of components from the previous stage, and their processing times are known in the production divisions of the previous stage where they are processed.

It is hardly practical to repeatedly construct schedules for the same components in the same production divisions. Constructing "framework" schedules does not require re-constructing existing schedules. In cases where schedule fragments have already been built for some of the components processed in a production division, these schedule fragments and their execution times are used to build "framework" schedules and are not built anew.

The feasibility of constructing a "framework" schedule is determined by the following circumstances. First, existing methods may be unsuitable for constructing schedules for processing components from formed groups in production divisions of a new stage, consisting of many production divisions from the previous stage. Using "framework" schedules, it is possible to construct schedules of very large dimensions. Second, schedules have already been constructed for all groups of components from the previous stage, and their processing times are known in the production divisions of the previous stage where they are processed.

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Indeed, at each stage of aggregation, beginning with the second, new divisions and component groups are formed for that stage.

Such divisions, as already noted, are formed by combining divisions from the previous stage, the composition of which is known for each formed division.

Each component group for a new stage also consists of component groups from the previous stage, which are processed in the same order in the same divisions of the current stage. The composition of these groups from the previous stage is also known for each formed component group for that stage. For each component group from the previous stage, the processing times and sequence in the divisions of the previous stage are known

Therefore, to determine the processing time for a formed component group for a new stage in the formed division of the new stage in which this group is processed, a "framework" schedule can be constructed.

This "framework" schedule is a schedule for processing groups of components from the previous stage, which are included in the formed group of components of the new stage, in the production divisions of the previous stage, combined into this division of the new stage.

After constructing the "framework" schedule, an "expanded framework" schedule it is possible to generate based on it using the scheme described above. From this "framework" schedule, a reasonably good schedule of work in the corresponding division is obtained using the "gluing" operation. The time of completion of processing of the last component on the division's equipment is selected as the component processing time in this division.

Furthermore, it is possible existing methods to used for construction of "framework" schedules in established divisions, since it is desirable to combine a very limited number of divisions from the previous stage when forming divisions.

As already noted, after each aggregation stage, the number of component groups cannot increase, which, as the number of divisions decreases, leads to a reduction in the dimensionality of the "framework" schedule. Therefore, after completing several aggregation stages, the number of component groups and the number of established divisions can be reduced so much that it will be possible to construct a "framework" schedule for virtually any mechanical engineering enterprise using existing methods.

Based on the constructed "framework" schedule, as already noted, without any principals difficulties it is possible to obtain a fairly good works schedule at any enterprise.

This schedule is suitable for managing and planning the enterprise's operations, and will also allow for determining the processing sequence and start and end times for all components on any equipment at the enterprise.

If, after completing the aggregation step, the resulting estimates indicate that creating a "framework" schedule may be difficult or unacceptably time-consuming, the next aggregation step is performed. This step is performed similarly to the previous aggregation step described above.

In this situation, the obtained estimates indicate that creating work schedules in these divisions using existing methods may be difficult. This situation typically arises from the poor selection of certain divisions with excessive equipment. Furthermore, such a situation may arise due to an excessive number of components for which processing schedules must be created, as well as due to the simultaneous presence of these factors.

When this situation arises, it is advisable to divide the equipment of each division for which creating a work schedule requires excessive time. The number of subgroups into which such divisions t is necessary to divide hat equipment of the same type is not allocated to different subgroups of the divided division. Otherwise, problems will arise when forming subgroups of components sent to these subgroups of the divided division for processing.

In such situations, it is necessary to divide the equipment of each division, for which scheduling work requires excessive time, into subgroups. It is advisable to choose the number and composition of such subgroups for this division so that equipment of the same type falls into only one subgroup, and not into different ones. Otherwise, problems will arise when forming subgroups of components that are sent to these subgroups for processing. Let us remind you that the formation of equipment groups, as already noted, does not entail changes in the administrative structure of enterprises and is only necessary for building work schedules

In addition, it is advisable to select these subgroups in such a way that, using existing methods, it is possible to create schedules for processing the corresponding subgroups of components within an acceptable time frame.

For each subgroup of equipment from a divided division, it is necessary to form subgroups of components that this subgroup of equipment should handle. These subgroups of components are necessary to form according to the rule described earlier from components directed to the divided division for processing. According to this rule, all components in each subgroup must be sent for processing in the same order to these subgroups of equipment and to other divisions of the enterprise. Furthermore, these subgroups must include all components sent for processing to the divided division.

After this, it is necessary to create a schedule for processing these subgroups of components. As before, it is advisable to verify the feasibility of creating such schedules in the formed subgroups using the boundary values of the methods employed, as described above. In cases where the boundary values are not exceeded, it is advisable to create such schedules using the existing methods and determine the processing completion times from them.

If all these schedules can be created, then the possibility of creating a “framework” schedule to process the subgroups of components in the subgroups of the divided division is verified.

If there are no exceedances of the boundary values, it is advisable to construct such a “framework” schedule. If the “framework” schedule is successfully constructed, an “expanded framework” schedule is created from it. After the “gluing” operation, a coordinated schedule of activities in the split division can be obtained from the “expanded” schedule, and from received schedule the completion times of these activities are determined. If any subgroups of the split division exceed the boundary values when processing the corresponding subgroups of components, these subgroups are divided into smaller subgroups, and the procedure described above is repeated for them.

If, when checking the feasibility of constructing a “framework” schedule for processing subgroups of components in the split division using existing methods, it turns out that difficulties may arise, then It is advisable the next aggregation step to performe according to the scheme described above.

5. PRINCIPLES AND FEATURES OF FORMING COMPONENT GROUPS

Let us briefly review the basic principles and features of component groups formation.

It is convenient to examine at first these principles using the example of forming first-level component groups. The formation of these component groups begins with the preliminary distribution of components by levels and their numbering. The level number assigned to each distributed component corresponds to the number of divisions it manufactured. The first level is assigned to components processed in a single division. The last k_1th level is assigned to components processed in the largest number of divisions within the enterprise. For forming component groups, they are numbered sequentially by component level, starting with the last k_1th level and ending with the components of the lowest level.

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bution of components by levels and their numbering. The level number assigned to each distributed component corresponds to the number of divisions it manufactured. The first level is assigned to components processed in a single division. The last k_1th level is assigned to components processed in the largest number of divisions within the enterprise. For forming component groups, they are numbered sequentially by component level, starting with the last k_1th level and ending with the components of the lowest level.

Component groups are typically formed by selecting a base component for the first group. The first base component for the first group being formed is typically the component of the last k_1th level, which is assigned the first number in the numbering process. Then, the next component of the last k_1th level is selected as the component to be inspected. After this, a comparison is made between the sequence of the enterprise divisions where the component being inspected and the base component of the group being formed are processed.

If the sequences of delivery for processing to the enterprise divisions of the base and inspected components match, then the component being inspected can be included in the group defined by this base component.

If these sequences differ, the sequences of delivery for processing to divisions of the base component and the next component to be inspected by number are compared. In this case, the previously inspected component will be the base component for the next group of components. Then, the first base component is compared with the next component to be inspected by number. If the sequence of delivery for processing to divisions of these components is the same, then the component being inspected is included in the group defined by this base component.

Otherwise, the sequence of delivery for processing to divisions of this inspected component it is necessary to compare with the sequence of delivery for processing for the base component.

If these sequences match, the inspected component It is advisable to include in the group of components defined by this base component, and to select the next component for inspecting.

The sequence of delivery for processing to divisions of each inspected component it is necessary to compare one by one with the sequence of delivery for processing to divisions of previously received base components.

If the delivery sequences for processing to divisions of the inspected component match the sequence of delivery of any of the previously received base components, the inspected component may be include in the group defined by this base component. Otherwise, the inspected component will be the base component for the next group.

This process continues until completion of the distribution into the formed groups of components of the k_1th level.

After completion of the distribution of level components into the formed groups, the distribution of components into the created and new groups of levels $(k_1 - 1), (k_1 - 2), \ldots,$ 2nd, and 1st components may be carry out almost in a similar manner. However, the sequence of delivery of components of lower levels for processing to the enterprise's divisions cannot coincide with the analogous sequences of basic components, since the latter are of a higher level. Therefore, it is advisable to consider the following options for including the inspected component in the formed group of components.

One option for including the inspected component in the formed group of components is that the sequence of its processing production divisions is a fragment in the similar sequence of the basic component.

A fragment in the sequence of divisions of a basic component here is understood to be the part of this sequence from the division with which the fragment begins to the division that ends it, without skipping divisions in the sequence. Another possibility for including the inspected component in the component group is that the sequence of delivery for processing to the enterprise divisions of the tested component is a subsequence of the similar sequence of the basic component.

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A fragment in the sequence of divisions of a basic component here is understood to be the part of this sequence from the division with which the fragment begins to the division that ends it, without skipping divisions in the sequence.

Another possibility for including the inspected component in the component group is that the sequence of delivery for processing to the enterprise divisions of the inspected component is a subsequence of the similar sequence of the basic component.

In this case, between divisions may be the divisions in which it is necessary to process the inspected and the main components, and divisions in which it is necessary to process the main components, but the inspected components does not.

When using the first principle of forming component groups, a larger number of such groups may be create. This can complicate the construction of a “framework” schedule for component processing at enterprises. In some cases, such difficulties can be quite significant.

Using the second principle of forming component groups, it is possible to obtain a smaller number of component groups, which simplifies the creation of a “framework” schedule for component processing at enterprises.

However, in this case, both when creating work schedules and during the manufacturing process, it is necessary to monitor components in groups that do not need to process in all divisions along the processing route for the basic components of these groups.

It is advisable to send such components to a warehouse if they do not require processing in the next division along the processing route for the group, and if they need to deliver in a timely manner from the warehouse to the divisions where they should continue processing as part of the group.

A very useful approach is to first apply the first principle of forming component groups. Then, if a very large number of component groups is obtained, combine some of them to reduce their number to an acceptable level. It is advisable to combine groups using the basic components of these groups.

A very useful approach is to first apply the first principle of forming component groups. Then, if it turned out that a number of component groups is very large, you should combine some of them to reduce their number to an acceptable level. It is advisable to combine groups using the basic components of these groups.

Furthermore, when forming component groups, it is advisable to take into account that many components, especially those processed in a small number of divisions, it is possible to include in different groups.

If such components to include in groups where it is necessary to process they in the divisions that equipment are most loaded with processing components already included in these groups, the processing time of the groups after their inclusion may increase significantly.

Let us consider the specifics of forming component groups in the second and subsequent stages of aggregation.

Component groups for a new aggregation stage are formed after the divisions in which they will be processed have been formed, and are formed from component groups from the previous stage.

However, at a new aggregation stage, due to the merger of several divisions, the level of the basic components of the previous stage and the component groups they define may change significantly.

Such a change may occur, for example, if a basic component of one group was processed in divisions of a certain stage, which, after aggregation, were included in different divisions of the next stage. Whereas a basic component of another group was processed in a larger number of divisions of the same stage, which were included in groups in a significantly smaller number of divisions or even in a single division of the next stage.

Therefore, these components, to form component groups for the new stage, it is necessary to distributed among new levels, taking into account the composition and number of divisions at that stage, and numbered.

In this case, as before, each level corresponds to the number of divisions at that stage in which the basic components distributed to that level are manufactured. The first level includes component groups processed in a single division at that stage. The last k_rth level, where r indicates the aggregation stage, includes components processed in the largest number of enterprise divisions formed at that aggregation stage.

The numbering of basic components begins with components at the last k_rth level, sequentially proceeds through lower component levels, and ends with components of the lowest level. Then, in accordance with the scheme described above, component groups for the new stage are formed.

6. SOME FEATURES AND PROPERTIES OF "FRAMEWORK" SCHEDULES AT MECHANICAL ENGINEERING ENTERPRISES

Let us consider the purpose and main properties of "framework" schedules for processing groups of components in mechanical engineering enterprise divisions.

Existing methods, as already noted, turned out unsuitable for creating work schedules at enterprises, especially those with a large amount of processing equipment and processed components.

Creating "framework" schedules allows us to solve the problems of creating work schedules at such enterprises.

The fact is that, according to the rules for drawing up "framework" schedules, the components of each formed group it is necessary to deliver for processing to divisions in accordance with the technological route of the group processing.

However, in each division along the processing route, the components of a group are processed according to its own technological processing route. Therefore, before starting processing in any division along the technological route of the group, all components of the group it is necessary preliminarily to process according to their technological processing route.

Furthermore, the dimensionality of "framework" schedules is significantly smaller than that of the original schedules, since in "framework" schedules, instead of several dozen units of equipment in each division, a single unit is considered—the division itself. Instead of dozens of units of components, only one unit is considered—the group of components processed in that division. Therefore, in many cases, such schedules, unlike original schedules, it is possible to construct using existing methods in a reasonable time.

"Framework" schedules have a very important property, allowing them to use quickly and easily generate a preliminary version of a work schedule for enterprises or large divisions.

Previously, the formation of such a schedule was described, which was called an "extended structure" or "unpacked structure" schedule. After the schedule "gluing" operation, this schedule can become a very good coordinated schedule for enterprises or large divisions. A coordinated schedule here, as already noted, is understood to mean a schedule that does not disrupt technology of component manufacturing.

The time required to complete work on such a "glued" schedule is significantly reduced compared to the time required to complete work on schedules prior to the "gluing" operation.

“Glued” schedules prove to be quite suitable for planning work at the enterprise and in its divisions, for obtaining substantiated information on the lead times of incoming orders, for organizing the work of the enterprise’s support services, etc.

It should also be noted that using “framework” schedules, it is possible to quickly obtain quite good upper estimates for order fulfillment times.

For construction “framework” schedules, as already noted, it is necessary to determine the processing times of component groups in the enterprise divisions processed these groups. These times it is possible to determine from the schedules for processing component groups in the corresponding enterprise divisions. Such schedules it is possible to construct independently of each other and in any order. Therefore, it is possible to parallelize their construction. Such parallelization will significantly reduce the time required to determine the processing times of component groups in enterprise divisions, which will result in a reduction in the time required to construct the “framework” schedule.

Furthermore, in the section summarizing the main properties of “framework” schedules, it is necessary to highlight the properties already mentioned in this work.

“Framework” schedules, like regular part processing schedules in production systems and areas, it is possible to represent using Gantt charts.

In the “framework” schedules, some of the already processed batches of components from the processing group can be transferred to an exempt division for processing, if this division is the next in the technological processing route of this group.

7. CONCLUSION

This paper proposes a method that utilizes sequential aggregation principles to create very large-scale work schedules for mechanical engineering enterprises. The proposed method allows for relatively simple parallelization of computations, significantly reducing schedules creation time.

Creating work schedules for enterprises with large amounts of equipment and processing a significant number of components will allow:

—to utilize the capabilities of scheduling theory methods to improve the enterprises work efficiency and reduce lead times for incoming orders;

—to create coordinated work plans and schedules that define the start and end times of all operations on all equipment of each enterprises.

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