

Production orders planning using additional backward pass scheduling approach

K Kalinowski, C Grabowik, G Ćwikła, I Paprocka and B Balon

Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: krzysztof.kalinowski@polsl.pl

Abstract. The paper focuses on the scheduling problem of minimizing flow time of production orders in job shop class systems. The proposed method supports both forward and backward scheduling and use additional backward pass for calculating the latest possible release date of a given production order. Depending on the adopted strategy, two or three stages are implemented in which the new due date and new release date is searched successively for each production order. Application of this approach causes that the scheduling of any order can be realized according to one of five ways. Four decision steps associated with the choice of the right method of order scheduling were distinguished. Examples illustrating the application of the proposed approach for the case of the forward and backward base strategy were also presented.

1. Introduction

Efficient implementation of production processes is one of the most important issues for planners in many production systems. This problem is particularly important in systems where production is multi-assortment, non-repetitive and variable in quantity. When accepting new, additional production orders for execution, the planner must be able to answer a number of key questions, e.g. Is it possible to execute a given order in a specified quantity and to complete it within a specified period? - or - Which date is acceptable and should be negotiated and agreed with a client? These decisions are binding and always involve risks.

The ability to precisely answer these questions requires a well-organized information system to provide access to current and actual state of the production system and the detailed status of performed tasks. It can be ensured by properly selected methods and tools for the production data acquisition [1]. These data may have a different character: deterministic, probabilistic and fuzzy; and depending on this, appropriate methods are required [2,3,4] although in many cases, when planning production, creating models based solely on deterministic data, with correspondingly frequent updating, is sufficient. One of the ways that allows for verification of the dates with given quantities is detailed scheduling, by determining the flow of potential orders in the system.

The process of detailed planning of orders and their operations can be performed in different ways, taking into account the specificity of a given enterprise and the characteristics of a given order. Most often, orders are planned according to one of the two main strategies: forward and backward. The



analysis of the advantages and disadvantages of applying both strategies became the basis for developing the method presented in this paper.

2. Forward and backward scheduling strategies

The choice regarding the application of an appropriate strategy for planning operations results from the evaluation criteria that are adopted in relation to a given production order. The strategy is associated with a given order, so different strategies may be used in the order set.

The forward method assumes that operations of a given order are inserted into the schedule in the sequence from the first to the last operation, according to precedence relationships, at the earliest available dates in required resources. As a result, the earliest possible dates of the operation are obtained and in consequence, the completion time for a given order. Forward strategy is most often used for urgent orders, which should be finished as fast as possible and it also allows determining real dates for completing new orders in the loaded production system, where other orders are already running. For qualitative evaluation of the schedule of orders planned by forward strategies, the criteria based on the completion times and flow times are most common [5,6,7]. For completion times there are minimisations of: $C_{max} = \max\{C_j\}$ (makespan) where C_j is completion time of j-th order, C_{av} (average completion time in the set of orders) or C_{sum} (aggregated completion time of all orders). For flow times respectively: $F_{max} = \max\{F_j\}$ where F_j - the flow time of j-th order; $F_j = C_j - r_j$, where r_j - release date of j-th order; F_{av} (average flow time in the set of orders) or F_{sum} (aggregated flow time of all orders).

In the case of backward strategy, operations are inserted into the schedule in reverse order, from the last operation to the first, starting from given due date. In this way the latest possible start date for a given order is obtained, date that guarantee its timely completion, on due date or earlier. This strategy allows to achieve smaller differences in the completion times of orders and the assumed due dates which can bring a number of benefits, like reduction of required warehouses capacity for finished products, later purchase and delivery of input materials, longer expiry date of products etc. However, if the due dates are set too early some operations may not be able to plan within an acceptable time period because they are scheduled into the past or before the acceptable release date. In such situations, orders are scheduled again, but according to the forward strategy, which results in achievable completion dates. The most common criteria used for qualitative evaluation of orders planned by backward strategies are performance measures based on due dates like lateness, tardiness, earliness, absolute and square deviations, unit penalty of late orders [5,6,8]. They are calculated as follows: lateness of j-th order: $L_j = C_j - d_j$; where d_j - the due date of j-th order, tardiness of j-th order $T_j = \max\{C_j - d_j, 0\}$, earliness of j-th order: $E_j = \max\{d_j - C_j, 0\}$, absolute deviation of j-th order: $D_j = |C_j - d_j|$, squared deviation of j-th order: $D_j^2 = (C_j - d_j)^2$, and penalty for delay of j-th order U_j ; $U_j = 0$ if $C_j \geq d_j$ and $U_j = 1$ if $C_j < d_j$.

On the basis of forward and backward strategies different combined strategies are created. In [9,10] bidirectional strategies have been proposed for scheduling resource constrained projects, where sets of operations can be described by a directed graph. They use both forward and back strategy at the same time for minimisation of project duration. In [11] they elaborated metaheuristic algorithm using forward and backward techniques in the implementation to the resource constrained project scheduling problem. The performance evaluation of the three types of heuristic algorithms forward backward and iterative in hybrid flow shop scheduling problem is presented in [12]. In their iterative approach scheduling are made on the forward and backward stages iteratively, using information obtained from the schedule of the other stage. In experiments they confirmed the higher effectiveness of the iterative algorithm.

3. Scheduling method with additional backward pass

In the proposed method, the possibilities of scheduling orders were extended beyond the classic forward and backward scheduling by applying an additional step in which the order can be rescheduled backward. This step is carried out in order to enable shortening the flow time of an order. Because the flow time of order strictly depends on the two parameters: due and release dates, this can only be done if it is possible to change the adopted earlier release date. As a consequence, it is possible to schedule a given order in 5 different ways. Figure 1 presents the possibilities of order planning based on the chosen strategy.

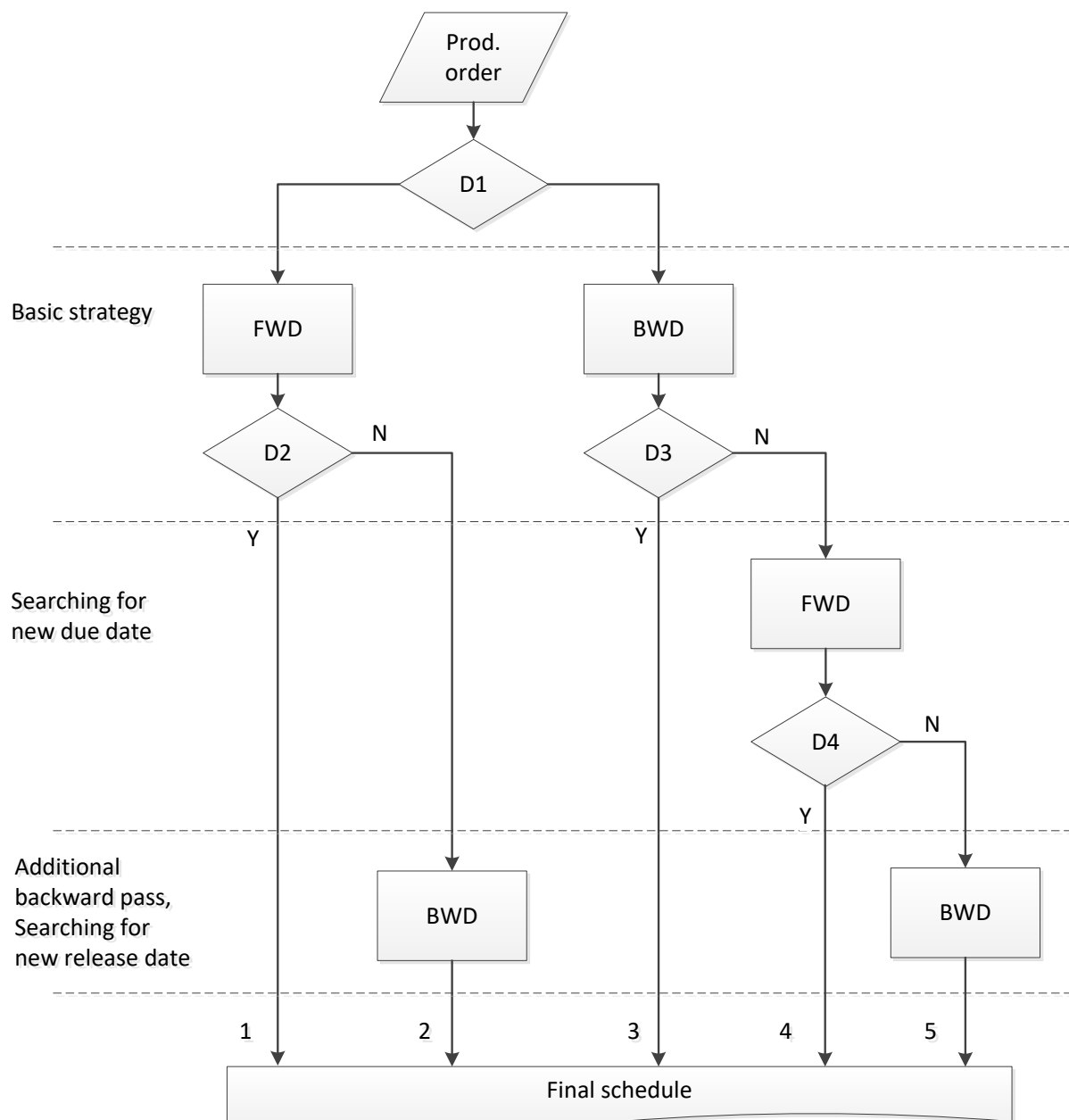


Figure 1. The possibilities (1-5) of scheduling a production order.

The forward and backward scheduling stages are marked by FWD and BWD respectively. There are four decision steps associated with the choice of the right method of order scheduling (D1-D4):

- D1 - related to the choice of the base strategy for the order, forward or backward,
- D2,D4 - associated with the attempt to shortening the order flow time after forward strategy,
- D3 - regarding the assessment of the acceptability of the solution.

Decision D1 should be made before the scheduling process, decisions D2 and D4 can be made before or during the scheduling process, depending on the adopted objective function and the degree of automation of the scheduling process. Decision D3 is made during the scheduling process, after first pass of backward scheduling.

3.1. Basic strategies

An order scheduling begins with the selection of the basic strategy forward or backward – decision step D1. This choice, as mentioned earlier, usually depends on the adopted evaluation criteria associated with the order, its urgency and the required date of their completion. It affects the further processing of the order.

If the forward strategy was the basic one, in D2 a decision is made: accept the designated solution (paths 1 in diagram) or if not then, having the designated completion time C_j of the order, execute the backward pass with $d_j = C_j$. If the basic strategy was backward, in D3 the solution is evaluated, and if feasible then is accepted (path 3), if not, it is run forward, starting from initial release date to determine the new due date.

3.2. Searching for the new due date

Unlike forward, using backward approach does not guarantee obtaining a feasible solution - if the due date is planned too early, some operations may be ‘scheduled into the past’ or before acceptable start time. In this case, if it is impossible to meet the due date, its real value should be determined. One way is to set it by forward scheduling. In many cases, order planning is terminated at this stage and it is implemented according to the forward strategy (path 4).

3.3. Additional backward pass

Additional backward scheduling can be implemented in both basic strategies forward and backward (path 2 and 5). The starting point is the last operation of the order, which stays at the previous scheduled time. Starting from the penultimate operation of an order, operations are moved sequentially back as close as possible to the next one. It is taken for searching new release date that enables shortening the real flow time of a given order in the system.

4. Example

The job shop configuration of the production system is considered. It consists of three resources M1-M3. Three production orders are implemented in the system; each of them consists of three operations. The table 1 presents characteristic, routes and operation times of each order. Order Z3 has the lowest priority and must be planned as the last.

Table 1. Operation times and routes of orders Z1-Z3.

	priority	release r_j	due date d_j	O1		O2		O3	
				M	t	M	t	M	t
Z1	1	0	9	M2	1	M1	2	M3	3
Z2	1	0	9	M1	2	M2	1	M3	2
Z3	2	0	9	M1	1	M2	2	M3	3

4.1. Case 1. Basic strategy - forward

In figure 2 three different schedules created in accordance with the above assumptions using forward strategy (path 1 in diagram 1) are shown. The first of them (2a) was created by planning successively each of the orders and all its operations, the first in the sequence Z1, Z2, Z3, the second (2b) in the sequence Z2, Z1, Z3. The third one (2c) was planned according to the earliest possible start date of an operation regardless of priority of the order (one of several possible solutions). Order Z3, which is the subject of consideration, is distinguished by a dark grey colour.

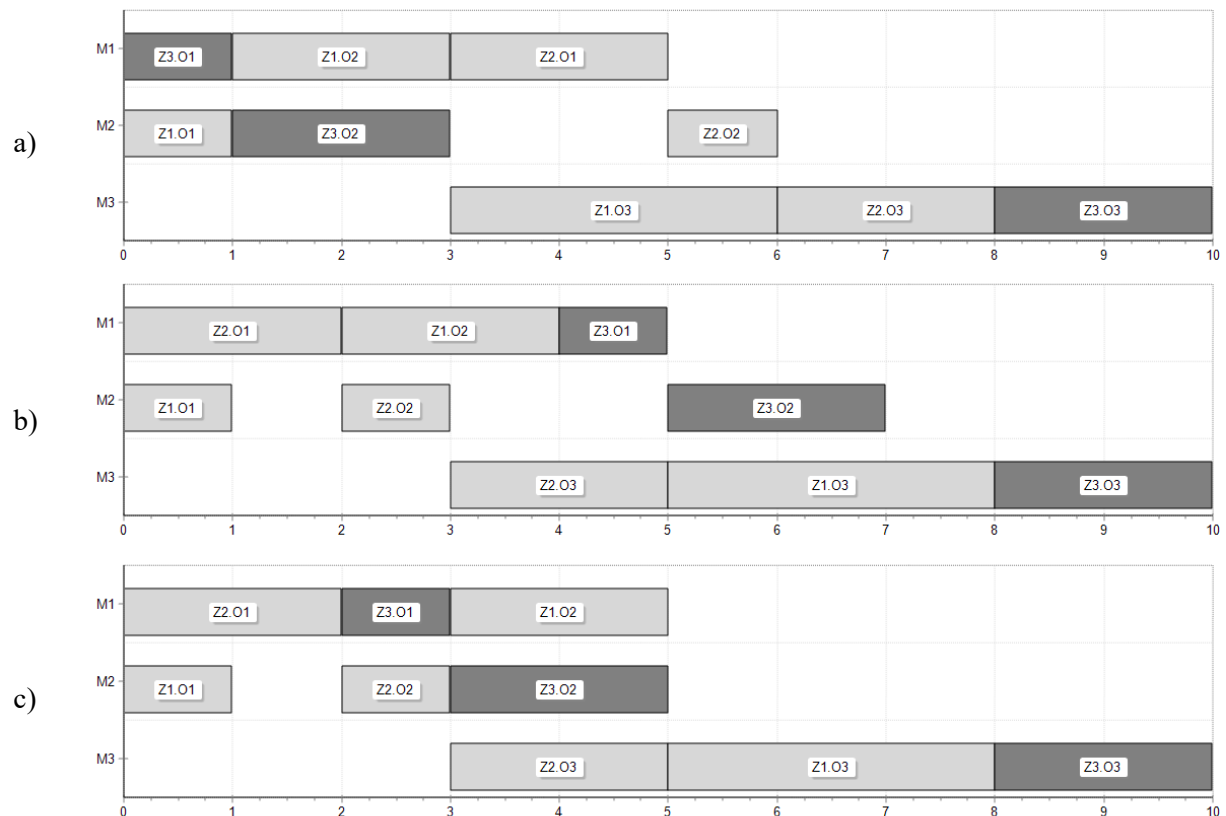


Figure 2. Selected solutions after applying forward strategy.

As shown in the Gantt charts above, depending on the solution, the flow time of order Z3 takes respectively from 6 to 10 time units. The use of "additional backward pass" (path 2 in figure 1) - allows shifting operations (Z3.O1) and (Z3.O2) closer to the last operation and can shorten this period to 5. The solution obtained in this way, on the basis of the solution presented in figure 2a is shown in figure 3.

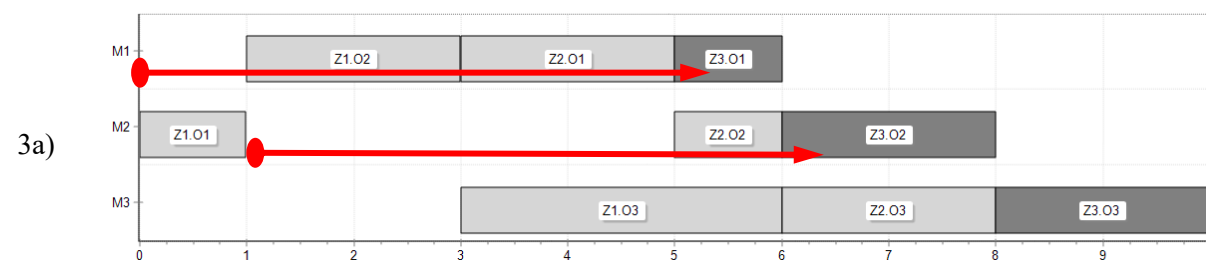


Figure 3. Solution 2a after additional backward pass of Z3.

4.2. Case 2. Basic strategy - backward

In the case of backward strategy for the same set of orders, with due dates for all orders $d_1=d_2=d_3=9$, the Z3 cannot be completely planned on time or earlier. In such situations, the order Z3 is scheduled forward, for obtaining the earliest feasible date for starting its operations (patch 4 in figure 1). After this stage, the order is already planned correctly with the new completion time $C_3=11$. In figure 4 schedules obtained at this forward stage for the sequence Z1, Z2, Z3 (4a) and Z2, Z1, Z3 (4b) are presented. The new, real due date for Z3 in both cases is in the 11th unit of time.

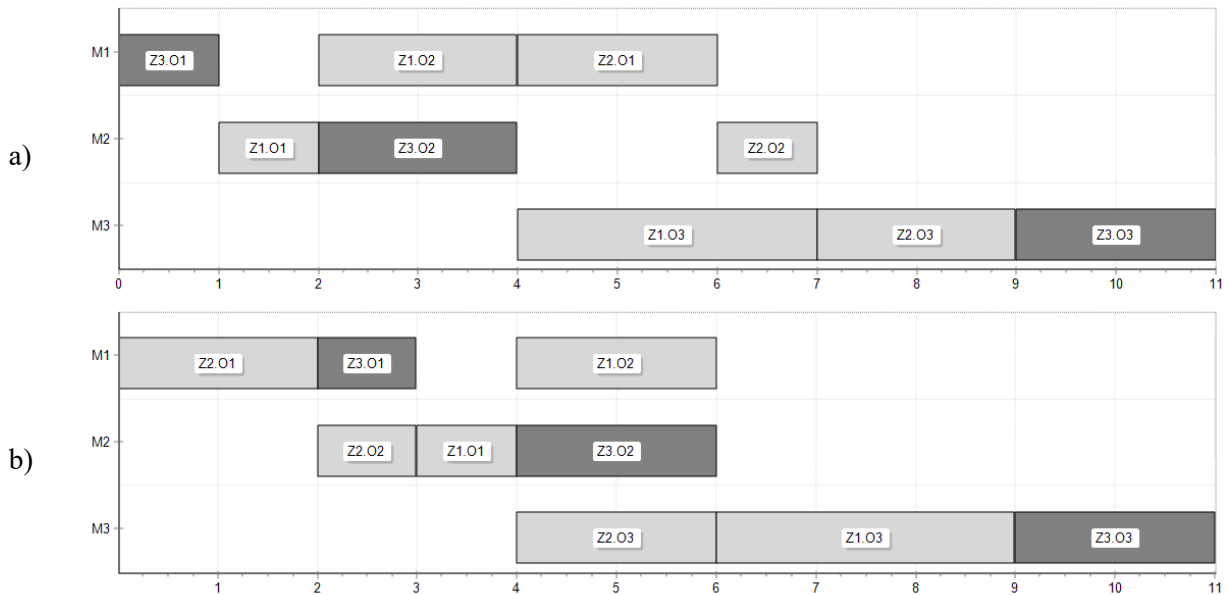


Figure 4. Selected solutions after applying backward strategy after forward pass of Z3.

As shown in the Gantt charts above, the flow time of Z3 can be significantly long, depending on the solution, in 4a) $F_3=11$, in 4b) $F_3=9$. The use of “additional backward pass” (path 5 in figure 1) also in this case, allows shortening the flow time of the order Z3 in the production system to $F_3=5$ time units. The solution obtained in this way, on the basis of the solution presented in figure 4a is shown in figure 5.

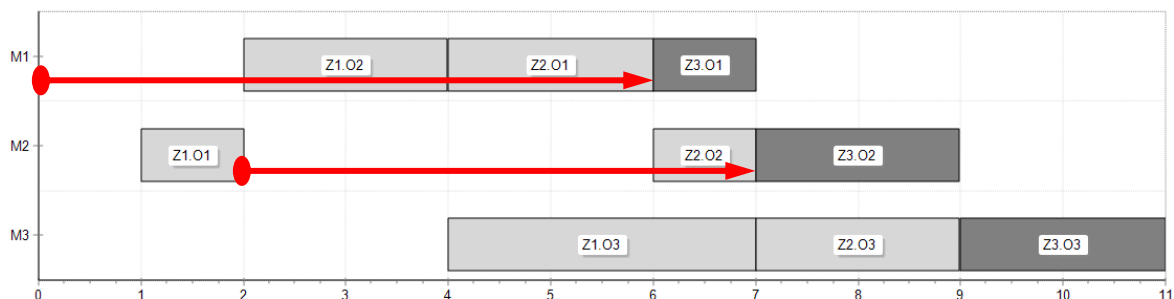


Figure 5. Solution 4a after additional backward pass of Z3.

5. Conclusions

The proposed method can improve selected performance measures of solutions obtained through one-pass forward or backward scheduling. Using an additional backward pass it can contribute to a reduction of the flow time of an order by determining new effective values for release date. If the flow time is not taken into account in evaluation criteria, this stage is not implemented. In the case of a basic backward strategy, the use of a second backward pass must be preceded by additional forward scheduling in order to determine the earliest possible end date. Benefits resulting from the application of the method entail the necessity of repeating the scheduling process once or twice for the considered orders, which can significantly increase the calculation time especially for more complex orders and for a larger number of them.

6. References

- [1] Ćwikła G 2016 Manufacturing information acquisition system methodology as a tool supporting data acquisition for production management. *Manufacturing 2014: Contemporary Problems of Manufacturing and Production Management, Poznan Univ Technol*, Poznan, 44–56
- [2] Kempa W M, Paprocka I, Kalinowski K and Grabowik C 2014 *Advanced Materials Research* **837** 116–121
- [3] Kujawińska A, Rogalewicz M, Diering M and Hamrol A 2017 *Advances in Intelligent Systems and Computing*, Springer, **571** 499–508
- [4] Hetmanczyk P M and Michalski P 2014 *Advanced Materials Research* **837** 399–404
- [5] Brucker P Scheduling Algorithms Fifth Edition Springer 2007
- [6] Pinedo L M Scheduling: Theory, Algorithms and Systems Fifth Edition Springer 2016
- [7] Webster S, Azizoglu M 2001 *Computers & Operations Research* **28** 127–137
- [8] Supithak W, Liman S D, Montes E J 2010 *Computers & Industrial Engineering* **58** 363–372
- [9] Klein R 2000 *European Journal of Operational Research* **127** 619–638
- [10] Scholl A, Klein R 1997 *INFORMS Journal on Computing Fall* **9** 319–334
- [11] Valls V, Quintanilla S, Ballest F 2003 *European Journal of Operational Research* **149** 282–301
- [12] Yeong-Dae K, Byung-Jun J, Jong-Ho S 2009 *J Heuristics* **15** 19–42