New Heuristic Algorithm for Flow Shop Scheduling with n-Jobs, Three Machines, and Two Robots Considering the Breakdown Interval of Machines and Robots Simultaneously

Mahdi Eghbali[a,*], Mohammad Saidi Mehrabad[b], Hassan Haleh[c]

[a]*MSc Student, Department of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

[b]*Professor, Department of Industrial Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran*

[c]*Assistant Professor, Department of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

Received 05 April 2013; Revised 03 December 2014; Accepted 24 June 2015

Abstract

In flow shop scheduling, the objective is to obtain a sequence of jobs which will optimize some well-defined criteria when processed in a fixed order of machines. In situations that robots are used to transport materials (material handler), breakdown of the machines and robots have a significant role in the production concern. This paper deals with a new heuristic algorithm for n-jobs, 3 machines, and 2 robots flow shop scheduling problem considering the breakdown interval of machines and robots simultaneously. This algorithm is based on Johnson algorithm. A heuristic algorithm is used to minimize total elapsed time, whenever mean weighted production flow time is taken into consideration. The proposed method is very easy to understand. Also, it provides an important tool for decision-makers. Furthermore, a numerical illustration is given to clarify the algorithm.

Keywords: Scheduling problems, Robots, Breakdown interval, Flow shop.

1. Introduction

The flow shop scheduling problem is one of the most popular machine scheduling problems with extensive engineering relevance(Wang et al. ,2012). In flow shop scheduling problems, the objective is to obtain a sequence of jobs which will optimize some well-defined criteria when processed on the machines. Every job will go on these machines in a fixed order of machines.

The number of possible schedules of the flow shop scheduling problem involving n-jobs and m-machines is $(m!)^n$. Every job will go on these machines in a fixed order of machines. Early research on flow shop problems is based mainly on Johnson's theorem, which gives a procedure for finding an optimal solution with 2 machines, or 3 machines with certain characteristics.

Johnson(1954) presented the algorithm for obtaining an optimal schedule, which minimizes makespan for n-jobs, two-machine problem, three-machine problem (for particular cases of n-jobs). The scheduling problem practically depends upon important factors, namely transportation time, breakdown effect, relative importance of a job over another job, etc. These concepts were studied by Ignall and Scharge (1965), Palmer (1965), Lomnicki(1965), Bestwick and Hastings (1976), Dannenbring (1977), Yoshida and Hitomi (1979), Nawaz et al. (1983), Sarin and Lefoka (1993), Koulamas (1998), Temiz and Erol(2004), etc. Heydari Poordarvish (2003) dealt with a flow shop scheduling problem where n jobs are processed in two disjoint job blocks in a string consisting of one job block in which order of jobs is fixed and other job block in which order of jobs is arbitrary. Lomnicki (1965) introduced the concept of flow shop scheduling with the help of branch and bound method. Further, the work was developed by Ignall and Scharge (1965), Brown and Lomnicki(1966), Chandrasekharan (1992) with the branch and bound technique to the machine scheduling problem by introducing different parameters. Singh et al. (2005) studied the optimal two-stage production schedule in which processing time and set-up time were both associated with probabilities including job block criteria. The concept of transportation time is very important in scheduling. Transportation can be done by robots. In situations that robots are used to transport materials (material handler), breakdown of the machines and robots has a significant role in the production issue. The concept of breakdown interval becomes very significant in the production process where a machine, while processing the jobs, gets a sudden breakdown due to failure of a component of machines for a certain interval of time, or the machines are supposed to stop their work for a certain interval of time due to some external imposed policies; for instance, cessation of the flow of electric current to the machines may be a

* Corresponding author Email address: iemehdieghbali@gmail.com

government policy due to shortage of electricity production. In each case, this may be well observed that working of machines is not continuous and is subject to interval of time. Hence, the problem becomes wider and more applicable to process/ production; industries obtain an algorithm, and it provides minimum utilization time, and hence minimum rental cost for them(Gupta, 2013).
This paper extends the study made by Gupta (2012). Many applied and experimental situations exist in our day-to-day working in factories and industrial production concerns, etc. In many manufacturing companies, different jobs are processed on various machines. These jobs are required to be processed in a specified order in machine shops A, B, C, etc. When the machines on which jobs are to be processed are planted at different places, the transportation time (which includes loading time, moving time, and unloading time, etc.) has a significant role in production concern. The breakdown of the machines and robots (due to delay in material, changes in release and tails date, tool unavailability, failure of electric current, the shift pattern of the facility, fluctuation in processing times, some technical interruption, etc.) has a significant role in the production concern.
The remainder of this study is organized as follows: Section 2 is dedicated to notations, assumptions, and definition of the problem. The proposed heuristic algorithm is explained in Section 3. Numerical experiments according to different characteristics appear in Section 4. Finally, conclusions and outlooks for future studies are given in Section 5.

2. Problem Formulation

2.1. Notations

S : Sequence of jobs 1, 2, 3… n
S_k : Sequence obtained by applying Johnson's procedure, k = 1, 2, 3, -------
M_j : Machine j, j= 1, 2, 3
M: Minimum makespan
A_{ij} : Expected processing time of *ith* job on machine *Mj*
FR_{i1}: Robot forward transportation time of i^{th} job between Machine1 and Machine2.
BR_{i1}: Robot backward transportation time of i^{th} job between Machine1 and Machine2.
FR_{i2}: Robot forward transportation time of i^{th} job between Machine2 and Machine3.
BR_{i2}: Robot backward transportation time of i^{th} job between Machine2 and Machine3.
L_R: Length of robot's breakdown interval.
L_M: Length of machines breakdown interval.
A'_{ij} : Processing time of i^{th} job after breakdown effect on machine j.
FR'_{i1}: Robot forward transportation time of i^{th} job after breakdown effect on robot between Machine1 and Machine2.
BR'_{i1}: Robot backward transportation time of i^{th} job after breakdown effect on robot between Machine1 and Machine2.
FR'_{i2}: Robot forward transportation time of i^{th} job after breakdown effect on robot between Machine2 and Machine3.
BR'_{i2}: Robot backward transportation time of i^{th} job after breakdown effect on robot between Machine2 and Machine3.
wi : Weight assigned to i^{th} job
f_i : flow time of ith job

2.2. Assumptions and Problem illustration

1. n jobs are processed through three machines M_1, M_2, and M_3 in the order of $M_1M_2M_3$, i.e., no passing is allowed.
2. There are material handler robots between Machine1 and Machine2 and material handler robots between Machine2 and Machine3.
3. Robots have forward and backward motions.
4. Any robot's comeback to its initial position after shifting from the first to second machine.

Our aim is to find the sequence of the jobs which minimizes the total elapsed time, whenever mean weighted production flow time is taken into consideration.

3. Proposed Algorithm

The following algorithm provides the procedure to determine optimal or near-optimal sequence to the problem P:

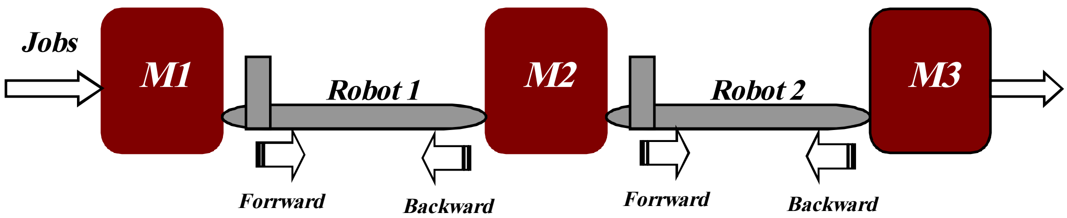

Fig.1. The problem illustration

Step 1: Calculate the $\sum$ (FR_{i1} + BR_{i1}) and $\sum$ (FR_{i2} + BR_{i2}).

Step 2: Check the structural condition

Max [A_{i1}+ $\sum$ (FR_{i1} + BR_{i1})] ≥ Min [A_{i2}+ $\sum$ (FR_{i1} + BR_{i1})]

or

Max [A_{i3}+ $\sum$ (FR_{i2} + BR_{i2})] ≥ Min [A_{i2}+ $\sum$ (FR_{i2} + BR_{i2})]

or both.

If these structural conditions are satisfied, then go to step 3, else the data are not in standard form to use Johnson algorithm.

Step 3 : Introduce two fictitious machines G and H with processing times *Gi* and *Hi* as given below:

$Gi = |\, A_{i1} - A_{i2} - \sum (FR_{i1} + BR_{i1}) - \sum (FR_{i2} + BR_{i2})|$

$Hi = |\, A_{i3} - A_{i2} - \sum (FR_{i1} + BR_{i1}) - \sum (FR_{i2} + BR_{i2})|$

Step 4: Compute *Minimum* (*Gi ,Hi)*

If *Min (Gi, Hi) =Gi*, then define $G'_i = Gi + w_i$ and H'i =*Hi.*

If *Min (Gi , Hi)=Hi*, then define $G'_i = Gi$ and $H'_i = Hi + w$.

If *Min (Gi ,Hi)=Hi=Gi*, then define G'i =$Gi + w$, H'i =*Hi.* or $G'_i = Gi$, and $H'_i = Hi + w$ arbitrarily

Step 5: Define a new reduced problem with *G''* and *H''*, where

$G'' = G / w$, $H'' = H / w$ i =1,2,3.....,n

Step 6: Using Johnson's procedure, obtain all the sequences for S_k by having minimum elapsed time. Let us call these be $S_1, S_2, \ldots, S_r$

Step 7: Prepare In-Out tables for the sequences S_1, $S_2, \ldots, S_r$ obtained in step 6. Let the mean flow time be minimum for sequence S_k.

Step 8: Form a modified problem with processing time A'*ij*, FR'_{i1}, BR'_{i1}, FR'_{i2}, and BR'_{i2}; i = 1, 2, 3, --- n; j= 1, 2,3.

Step 8.1: effect of machine breakdown interval

If the machine breakdown interval L_M = (a, b) has effect on job *I*, then $A'ij = Aij + L_M$; Where L_M=b – a, the length of machine breakdown interval

If the breakdown interval L_M = (a, b) has no effect on ith job, then A'ij =*Aij*.

Step 8.2: effect of robot's breakdown interval

If the robot's breakdown interval L_R =(c, d) has effect on robots 1 or 2 or both, then $FR' = FR + L_R$ *or* $BR' = BR + L_R$ *or both;* Where L_M = d – c, the length of machine breakdown interval.

If the robot's breakdown interval L_R =(c, d) has no effect on ith job, then $FR' = FR$ *or* $BR' = BR$ *or both*.

Step 9: Repeat the procedure to get the optimal sequence for the modified scheduling problem using steps 2 to 6. Determine the total elapsed time.

Step 10: Find the performance measure studied in weighted mean flow time defined as $F = \sum_{i=1}^{n} w_i f_i \Big/ \sum_{i=1}^{n} f_i$, where f_i is flow time of i[th] job.

4. Numerical Example

In this section, we provide one numerical example and the proposed algorithm is compared wih the two results.

Consider the following flow shop scheduling problems of 5 jobs and 3 machines, in which the processing time, robot forward and backward transportation times, and weight of jobs are given in Table 1, (Gupta (2012)). Machine breakdown interval is L_M=(30,35), and robot's breakdown interval is L_R=(17,20).

Find optimal or near-optimal sequence and also calculate the total elapsed time and mean weighted flowtime.

Solution:

Step 1: The results of step 1 are shown in Table 2.

Step 2: considering Table 3, the structural conditions of step 2 are satisfied.

Table 1

The expected processing times for the machines and robots

Jobs i	A_{i1}	FR_1	BR_1	A_{i2}	FR_2	BR_2	A_{i3}	w_i
1	16	4	2	18	3	1	12	2
2	12	5	3	14	5	3	12	4
3	10	3	1	11	4	2	14	3
4	14	4	2	10	6	4	12	5
5	12	6	4	12	4	2	10	1

Table 2

The results of step 1

job i	A_{i1}	FR_1	BR_1	$\Sigma(FR_1+BR_1)$	A_{i2}	FR_2	BR_2	$\Sigma(FR_2+BR_2)$	A_{i3}	w_i
1	*16*	*4*	*2*	*6*	*18*	*3*	*1*	*4*	*12*	*2*
2	*12*	*5*	*3*	*8*	*14*	*5*	*3*	*8*	*12*	*4*
3	*10*	*3*	*1*	*4*	*11*	*4*	*2*	*6*	*14*	*3*
4	*14*	*4*	*2*	*6*	*10*	*6*	*4*	*10*	*12*	*5*
5	*12*	*6*	*4*	*10*	*12*	*4*	*2*	*6*	*10*	*1*

Table 3
The results of step 2

job i	$A_{i1}+\Sigma(FR_1+BR_1)$	$A_{i2}+\Sigma(FR_1+BR_1)$	$A_{i3}+\Sigma(FR_2+BR_2)$	$A_{i2}+\Sigma(FR_2+BR_2)$
1	*22*	*24*	*16*	*22*
2	*20*	*22*	*20*	*22*
3	*14*	*15*	*20*	*17*
4	*20*	*16*	*22*	*20*
5	*22*	*22*	*16*	*18*
	22	*15*	*22*	*17*
	MAX	*MIN*	*MAX*	*MIN*

Step 3: the two fictitious machines G and H with processing times *Gi* and *Hi* are shown in Table 4.

Table 4
The results of step 3

job i	G_i	H_i	w_i	$\min(G_i, H_i)$
1	12	16	2	12
2	18	18	4	18
3	11	7	3	7
4	12	14	5	12
5	16	18	1	16

Step 4 **:** The new reduced problem is shown in Table 5.

Table 5
Minimum (Gi ,Hi)

job i	G'_i	H'_i
1	14	16
2	22	18
3	11	10
4	17	14
5	17	18

Step 5:The new reduced problem is shown in Table 6.

Table 6
The reduced problem with G"i and H"i

job i	***G"i***	***H"i***
1	*7*	*8*
2	*5.5*	***4.5***
3	*3.7*	***3.3***
4	*3.4*	***2.8***
5	***17***	*18*

Step 6 : Using Johnson's method, the optimal sequence is 1-5-2-3-4

Step 7: The In-Out table for the sequence S ' is as shown in Table 7. Gantt chart without the effect of machine breakdown interval and robot's breakdown interval is shown Fig.2.
Total Elapsed Time=107
Mean Weighted Flow Time=54.4
Step 8: The modified problem after the effect of machine breakdown interval (30,35) and robot's breakdown interval (17,20) is shown in Table 8.
Step 9: Now, on repeating the procedure to get the optimal sequence for the modified scheduling problem using steps 2 to 7, we have got the sequence S2 : 2-1-5-3-4. Compute the in-out table for S2 and get the minimum total elapsed time.. (see figure 3)
Step 10: Hence, the total elapsed time is 118 units and Mean Weighted Flow Time=59.3

Table 7
The In-Out table for the sequence S '

job i	M_1		FR_1 Interval		FR_1	BR_1 Interval		BR_1	M_2		FR_2 Interval		FR_2	BR_2 Interval		BR_2	M_3		w_i
	In	Out							In	Out							In	Out	
1	0	16	0	4	4	4	6	2	20	38	0	3	3	3	4	1	41	53	2
5	16	28	6	12	6	12	16	4	38	50	4	8	4	8	10	2	54	64	1
2	28	40	16	21	5	21	24	3	50	64	8	13	5	13	16	3	69	81	4
3	40	50	24	27	3	27	28	1	64	75	16	20	4	20	22	2	81	95	3
4	50	64	28	32	4	~~	~~	~~	75	85	22	28	6	~~	~~	~~	95	107	5

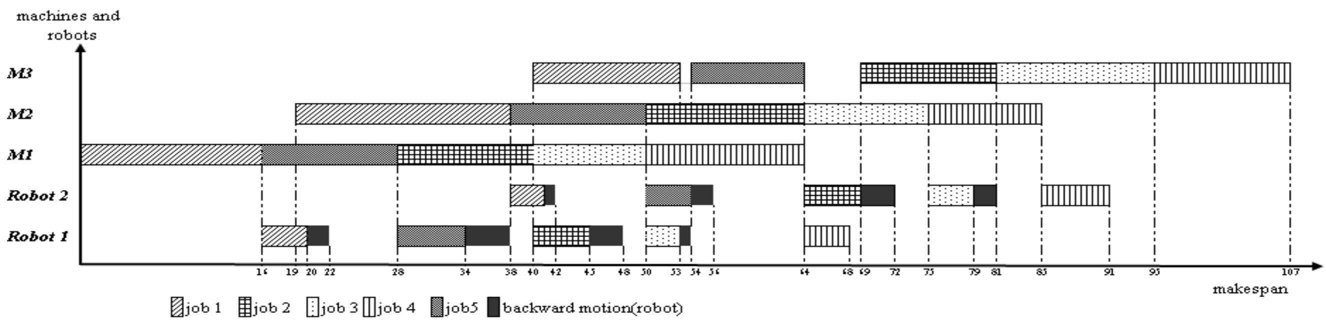

Fig. 2. Gantt chart without the effect of machine breakdown interval and robot's breakdown interval

Table 8
The data of modified problem

job i	M_1 A_{i1}	FR_1	BR_1	M_2 A_{i2}	FR_2	BR_2	M_3 A_{i3}	w_i
1	*16*	*4*	*2*	*23*	*3*	*1*	*12*	*2*
2	*17*	*8*	*3*	*14*	*5*	*6*	*12*	*4*
3	*10*	*3*	*1*	*11*	*7*	*2*	*14*	*3*
4	*14*	*4*	*2*	*10*	*6*	*4*	*12*	*5*
5	*12*	*6*	*4*	*12*	*4*	*2*	*10*	*1*

Table 9
The In-Out flow table for the modified scheduling problem

Job i	M_1		FR_1 Interval		FR_1	BR_1 Interval		BR_1	M_2		FR_2 Interval		FR_2	BR_2 Interval		BR_2	M_3		w_i
	In	Out							In	Out							In	Out	
2	0	17	0	8	8	8	11	3	25	39	0	5	5	5	11	6	44	56	2
1	17	33	11	15	4	15	17	2	39	62	11	14	3	14	15	1	65	77	1
5	33	45	17	23	6	23	29	4	62	74	15	19	4	19	21	2	78	88	4
3	45	55	29	32	3	32	33	1	74	85	21	28	7	28	30	2	92	106	3
4	55	69	33	37	4	~~	~~	~~	85	95	30	36	6	~~	~~	~~	106	118	5

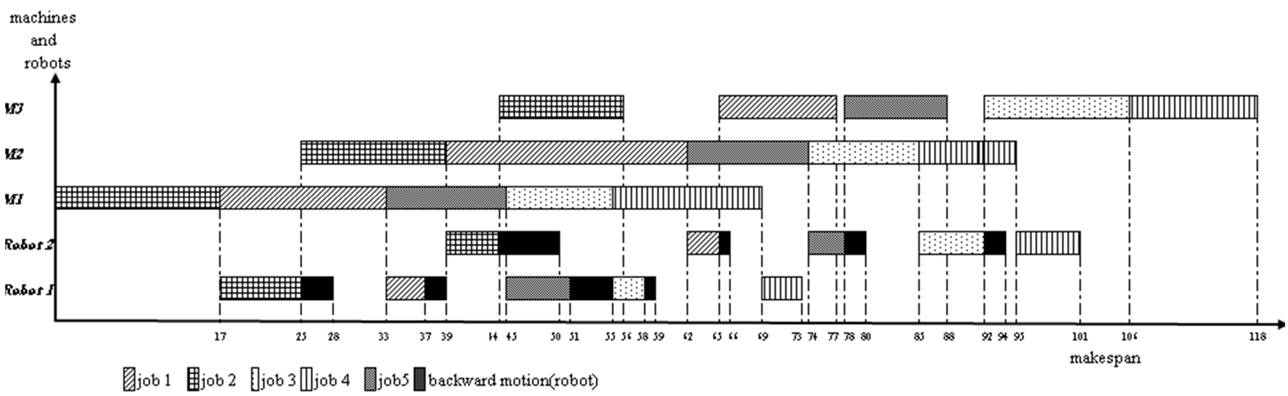

Fig. 3. Gantt chart after the effect of machine breakdown interval and robot's breakdown interval

Finaly, the proposed algorithm is compared with the simulation results without considering the effect of machine and robot's breakdown interval. It should be noted that in simulation, breakdown intervals are uniformly distributed. In simulation method calculation, these results are the average of 20 run times. The data for rest of the problems in this section are obtained similar to those of numerical example are given. In this section final results are shown in Table 10.

5. Conclusion

In this paper, we proposed a new heuristic solution based on the flow shop scheduling problem (number of machine =3) in which the effects of machine and robot's breakdown interval are considered simultaneously.
Mentioned algorithm sequence the jobs which minimizes the total elapsed time, whenever mean
weighted production flow time is taken into consideration. We compared the results with simulation without considering machine breakdown. Also, it is done bye assumption of having 3 machined and 2 robots.

Table 10
Result of the proposed algorithm with tho methods

Number of jobs	Total elapsed time		Average elapsed time
	Without breakdown	With breakdown	Simulation
2	77	64	70
3	96	85	91
4	108	97	103
5	118	107	110

References

Bestwick, P.F. & Hastings, N.A.J., (1976). A new bound for machine scheduling. *Operational Research Quarterly*, 27, 479-490.

Brown, A.P.G. & Lomnicki, Z.A., (1966). Some applications of the branch and bound algorithm to the machine scheduling problem. *Operational Research Quarterly*, 17, 173-182.

Chandramouli, A.B., (2005). Heuristic approach for N job 3 machine flow shop scheduling problem involving transportation time, break-down time and weights of jobs. *Mathematical and Computational Application*, 10(2), 301-305.

Dannenbring, D.G., (1977) .An evaluation of flow shop sequencing heuristics. *Management Science*, 23(11), 1174-1182.

Gupta, D., (2012). Branch and Bound Technique for three stage Flow Shop Scheduling Problem Including Breakdown Interval and Transportation Time. *Journal of Information Engineering and Applications*, 2(1),24-29.

Gupta, D. & Singh,S.,(2013). Specially structured n-job 2-machine flow shop scheduling model with breakdown interval and weightage of jobs. *International Journal Of Engineering Sciences & Research Technology*,2(8),13-18.

Heydari Poordarvish, A., (2003). On flow shop scheduling problem with processing of jobs in a string of disjoint job blocks: fixed order jobs and arbitrary order jobs. JISSOR ,(24) ,1- 4.

Ignall, E., & Schrage, L., (1965). Application of the branch-and-bound technique to some flow shop scheduling problems. *Operations Research*, 13, 400-412.

Johnson, S. M., (1954). Optimal two and three stage production schedule with set up times included. *Nay Res Log Quart* ,(1), pp 61-68.

Koulamas, C., (1998). A new constructive heuristic for the flow shop scheduling problem. European Journal of Operations Research, 105, 66-71.

Lomnicki, Z.A., (1965). A branch-and-bound algorithm for the exact solution of the three-machine scheduling problem. *Operational Research Quarterly*, 16, 89-100.

Nawaz, M., Enscore, Jr.E.E., & Ham, I., (1983). A heuristic algorithm for the m-machine n-job flow shop sequencing problem. *OMEGA International Journal of Management Science*, 11, 91-95.

Palmer, D.S., (1965). Sequencing jobs through a multi-stage process in the minimum total time-a quick method of obtaining a near-optimum. *Operational Research Quarterly*, 16(1), 101-107.

Sarin, S., & Lefoka, M., (1993). Scheduling heuristics for the n-job, m machine flow shop. *OMEGA*, 21, 229-234.

Singh, T.P., Rajindra, K., & Gupta, D. (2005). Optimal three stage production schedule the processing time and set up times associated with probabilities including job block criteria. Proceeding of National Conference FACM, 463-470.

Temiz, I. & Serpil, E., (2004). Fuzzy branch and bound algorithm for flow shop scheduling. *Journal of Intelligent Manufacturing*, 15, 449-454.

Wang, L., Pan, Q.K., Suganthan, P.N., Wang, W.H., & Wang, Y.M., (2010). A novel hybrid discrete differential evolution algorithm for blocking flow shop scheduling problems. *Computers and Operations Research*, 37, 509-520.

Yoshida, T., & Hitomi, K., (1979). Optimal two stage production scheduling with setup times separated. AIIE Transactions, 11(3), 261-263.

This article can be cited: Eghbali, M., Saidi Mehrabad, M. & Haleh, H. (2017). New Heuristic Algorithm for Flow Shop Scheduling with n-Jobs, Three Machines, and Two Robots Considering the Breakdown Interval of Machines and Robots Simultaneously. *Journal of Optimization in Industrial Engineering*. 10(21), 41-46.

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