Optimizing Crimping Operations in Cable Assembly Shops

AHMET N. CERANOGLU*, EKREM DUMAN
Industrial Engineering Dept
Dogus University
Acibadem Kadikoy 34722 Istanbul
TURKEY
* Correspondence: A.N. Ceranoglu, Dept. Ind. Eng., Dogus University, Acibadem Zeamet Sok. 21, 34722 Istanbul Turkey, +90 216 544 55 55 (Ext.:1311)

Abstract: Long setup times are incurred in the crimping operation of automotive cable assembly shops. Different heads are used to crimp different connectors to the end of operators where the heads on a machine can be changed one by one. These heads are quite expensive and the manufacturers avoid having more then one of each type. In such a manufacturing environment where multiple crimping machines are used the primary objective is to minimize the total time spent to setups. Also, it is desirable to have a schedule so that simultaneous use of the same head on more than one machine is avoided. In previous research there are some works on the first objective and two successful heuristics are proposed. In this study we cope for the second objective also and propose two comparable heuristic algorithms.

Key-words: TSP (1,2), Cable Assembly, Heuristics

1 Introduction

One of the bottleneck operations in automotive cable assembly shops is the crimping operation. In this operation continuous feed cables are fed to the cutting-crimping machines where the cable is cut to size, its ends are stripped and connectors are crimped to the ends. All these sub-tasks are performed in the same machine cycle (i.e. simultaneously). We name these set of tasks as the crimping operation since it is the most characteristic one. Although some minor setups are incurred where the cable type or the strip length are changed these setups are quite small and negligible as compared to the crimping head changed. For each type of connectors a different head is required and it takes about half an hour to change and mount a new head on the machine. Furthermore, due to some technical characteristics of the manufacturing, two heads cannot be changed simultaneously and it takes twice time to change two of them. Thus, it is important to minimize the time spent to setups if one wants to get the maximum utilization from these machines.

This same problem was tackled by Duman et al. (2005) and the setup minimization problem was modeled as a TSP (1,2) [1]. This is a traveling salesman problem where the distance between two cities is either one (corresponding to half an hour or change of one head) or two (corresponding to one hour or changing both heads). The classical TSP is a well-known problem and has been extensively studied in the literature. There are even books written on it [2]. Similar to the classical TSP, the TSP(1,2) is also NP-hard [3]. We refer the reader to the works of Papadimitrious and Yannakakis (1993), Fotakis and Spirakis (1998) and Duman et al (2005) for more information on TSP (1, 2) and/or Ceranoglu et al (2007) [1] [4] [5] [6].

Actually, in the practical setting undertaken there were five cutting machines but in their study Duman et al assumed single machine, determined a production sequence of cables and then distributed the workload to five machines following the sequence obtained [1]. If five machines are assumed as part of the solution then the formulation of the problem would turn out to be a vehicle routing problem (VRP) where the weekly production hours will be taken as the vehicle capacities. The VRP is one of the most difficult problems of combinatorial optimization and is NP-hard [7].

In such environments the crimping heads are quite expensive tools and thus the investors try to avoid buying additional copies of heads. In this regard, the production schedule should be arranged so that simultaneous requirement of the same head type by more than one machine in the shop is avoided. This constraint as added as a side constraint makes the problem much more complex. One approach of attacking this problem is first to ignore this side constraint, solve the setup minimization problem and then modify the resulting schedule to satisfy the side constraint (ie. to eliminate the cases where the same head appears on the schedule of more than one machine at the same time). Even this second phase of solution is brings in a very complicated problem to solve. In this study, we will stick with this approach but we will bring a solution (we will leave it as a future work). However, we will compare the solution algorithms that we propose for the setup minimization problem in their ability or ease of applicability of second phase procedures.

The organization of the remaining of this paper is as follows. In the next section we will summarize our own previous work on this problem. Then in section three we will propose two new algorithms for the multiple machine case. The experimentation and the comparison of the algorithms in regards to both objectives will be given in section four. This will be followed by summary and conclusions in section five.

2 Previous Work

Duman et al (2005) tackled the same problem of setup minimization and suggested an heuristic algorithm which they named *Popular Connectors First* (PCF). In this study we rename their algorithm as MPCF (*Most Popular Connectors First*) to distinguish its difference from the other algorithms that have been proposed.

The MPCF algorithm starts with the identification of the most popular connector type (the connector type having the highest number of usage among the products). The products having this type of connector are produced as a group. Then, the next popular connector type within the remaining list of products is identified and the products having this type of connector are produced next. In passing from one group of products to the next, a connector type that is common to both groups is used. In order to achieve this, the cables using this common connector type are moved to the end of the first group while they are moved to the beginning of the next group. This assures a passage of distance one between the two groups. This procedure is continued until all products are sequenced.

The MPCF algorithm was applied to a bunch of quasi-real life problems and major reductions in total setup time are obtained as compared to the industrial practice. In their setting Duman et al (2005) assumed a single machine where they supposed that the sequence of jobs would be distributed to five available machines in the shop floor [1].

The following statement was used as an advantage of the MPCF. *As it groups the products according to connector types and sequences the products in a group consecutively, the probability of assigning a head to more than one machine will be quite small. That is the second objective will almost be automatically met and only a little modification on the resulting sequence may be required. Actually, one can consider a different algorithm (e.g. modeling the problem as a multiple TSP(1,2) and finding a solution to it), which does not sequence all the connectors of one type consecutively as a group but instead assigns it to different places throughout the sequence. It is probable that, such an algorithm may find a better solution to the setup minimization problem. However, this time it is more probable that the same connector type (meaning head) is required by more than one machine at the same time. In this case, the modification of the resulting sequence would not be easy and at the end of modifications, the solution may become worse. On the other hand, the modification on a MPCF sequence is easier, since all but the first and the last products in a group can be re-arranged in any order without increasing the cost. These issues make the MPCF algorithm advantageous.*

Following this statement and being keen on a better algorithm in terms of setup minimization, Ceranoglu et al (2007) developed the LPCF (Least Popular Connectors First) algorithm [6]. Contrary to MPCF, LPCF starts with the least popular connectors and put them in the sequence. At each step it targets to produce the next least popular connector but in doing so it utilizes the popular connectors if they help a distance one passage to the target. As stated by Ceranoglu et al (2007), the LPCF algorithm has several basic strengths [6]. *Firstly, as it considers the connector types in an increasing order of their popularity, the chance of arriving at a passage with distance one is relatively high in the earlier iterations since connectors with high popularities have not been used up. Secondly, because the connectors with higher popularities are left to the end they again will have the largest probability of providing a distance of one among themselves.*

The LPCF algorithm has been applied to the same set of problems of Duman et al (2005) and the results were parallel to the expectations. That is, the LPCF algorithm was able to obtain lower set times but the sequences obtained were indicating a poorer performance in terms of the second objective. In other words, the simultaneous requirement of some heads on more than one machine was more probable under the use of LPCF. The results will later be given in table 1 below [1].

The new approaches that we propose are described next.

3 Multiple machine scheduling

For both of the MPCF and LPCF algorithms described in the previous section the number of machines available was ignored and the production sequence was obtained as if there were only one machine. After obtaining this sequence, the total workload of the cables to be produced is distributed to machines. Starting with the lowest indexed machine, the cables on top of the sequence which are sufficient to fill the machine for the planning period are taken and assigned to the machine with the same order. Then the other machines are filed accordingly. Note that if the cables at hand are not much enough to fill all the machines then there will remain some idle capacity on the last machine.

As an alternative, the available workload could be distributed to machines as equally as possible (line balancing) and then the production sequence can be determined for each machine separately.

Assuming single machine as above, in determining the production sequence one can expect less double setups since there are many alternatives (as compared to fewer alternatives of multiple machine approach) one of which can provide a single setup passage to the next product.

Although the multiple machine approach could result with a higher setup time, it may have some practical advantages. For example assume the case where a new order arrives during the planning period which needs to be integrated with the current schedule. In the single machine approach it needs to be put on the last machine and for our new product most probably a double setup will incur. But in the multiple machine approach we have all machines as a potential machine to produce the new order. This time the chance of distance one passage for the new product is considerably higher.

In this study, we use the LPT (longest processing time) heuristic to balance the workload on the cutting machines. The LPT heuristic is quite simple is known to be very successful in parallel machine scheduling (or, line balancing). With this heuristic we sort the connectors according to their total production time (among all cables requiring that connector) and starting with the most used connectors we assign them to machines one by one, each time to the machine which has the least load assigned. After applying LPT we end up with more or less the same workload on the machines. However, note that the diversity of different connector types on machines is less this time.

As the next step, the cable types on each machine should be sequenced with the objective of minimizing the setup time on the machine. For this purpose we have tried both the MPCF and the LPCF algorithms which were studied before for the single machine approach. The results are given under the balancing columns of table 1.

4 Comparison of the Approaches

As explained above in the introduction section, for such manufacturing environments there are two objectives. Firstly the non-productive setup times should be minimized. Secondly, since the crimping heads are expensive tools the manufacturer should not be obliged to own multiple copies of different head types.

To determine if a head appears on several machines simultaneously (that is, if there is a crossing) we need to know the exact schedule. In other words, we need to know the start and end times of cables (and, connectors) on the machines. In our case, since we do not have the production quantities of the cables but without loss of generality we assumed that each of them will be produced in the same amounts. In our experimental setting where 200 cable types which are composed of 50 connector types are produced on five machines in a week this corresponded to half an hour production time for each cable type. Also in this setting, about 40 cable types are produced on each of the five machines and we assumed that the start and end times of cables on all machines are the same. Thus, the position number in the sequence determines the schedule and if the same connector type appeared on the same position number on more than one machine we assumed that there is a crossing. The number of crossings determined using this definition is also given in table 1.

Table 1. Comparison of the approaches.

Experiment	Division				Balancing			
	MPCF		LPCF		MPCF		LPCF	
	Setup	Crossings	Setup	Crossings	Setup	Crossings	Setup	Crossings
1	212	0	205	31	210	0	209	6
2	212	0	205	21	206	5	210	8
3	210	0	205	30	212	2	209	7
4	210	4	207	15	208	0	211	12
5	213	1	205	45	213	2	209	8
6	214	0	205	21	213	0	207	11
7	211	0	205	21	208	2	207	5
8	212	0	205	15	211	4	210	11
9	213	0	205	14	209	2	208	8
10	213	0	207	10	212	1	213	15
Average	212,0	0,5	205,4	22,3	210,2	1,8	209,3	9,1

In table 1, the results given under the division columns are for the single machine approach where a single production sequence is determined and then divided to five machines. Multiple machine approach is named as balancing here. For both approaches both algorithms MPCF and LPCF are experimented and their performances are recorded using two measures: total setup time (setup) and the number of crossings (crossing). From the results we can put some summary observations:

Firstly, in parallel to the discussions in the previous work, the MPCF algorithm produces fewer crossings. This is true for both division and balancing approaches. Secondly, again as expected, the LPCF algorithm resulted in less setup time but the high crossing may not warrant its application. Thirdly when we compare the division and balancing approaches we see that the number of crossings is fewer but the setup time is somewhat higher. We could expect fewer crossings since in the balancing phase the set of connectors on the machines are separated to some extent. We could also expect higher setup times since in preparing the sequence the probability of finding a distance one passage is less probable since the diversity of connectors on machines are less than the division approach.

After determining the crossings one might try to eliminate them by making changes on the production sequences on machines. This is no way an easy task. While trying to eliminate a crossing on two machines one can create new crossings on other machines or even on the same machines. However, referring to the discussions given in Duman et al (2005), this task would be much easier in MPCF algorithm. Thus, as a final recommendation we can say that, one can try both approaches and both algorithms and if the setup time in MPCF is not considerably more than the other, he can continue with that solution; eliminate the crossings and implement the resulting sequence [1].

5 Summary and Conclusions

In this study, the optimization issues in a cable assembly shop are undertaken. In this shop the main objective is to minimize the setup times on the cutting machines. However since the heads used on these machines are quite expensive tools, the production schedule should be one avoiding simultaneous use of the same head type on more than one machine.

For the solution of this problem two different heuristic algorithms are compared where one of them is more successful in terms of setup minimization (LPCF) and the other one gives fewer crossings (MPCF). We conclude that since eliminating the crossings is not an easy task at all, one can use the MPCF algorithm is its setup time is not much worse than the LPCF algorithm.

As a future work we plan to focus on the crossing elimination problem, develop a procedure for it and integrate it to the MPCF and LPCF algorithms. This way we would be able to give a complete solution to cable shop optimization problem.

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