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Optimization of Assembly Line Balancing with Resource Constraint using NSGA-II: A Case Study

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Abstract

Abstract Assembly line balancing type-e problem with resource constraint (ALBE-RC) is an attempt to assign the tasks to a minimal number of workstation with minimum cycle time by considering the resource constraint. Due to rapid growth in manufacturing and limited number of resources in industry, all the tasks that used the same resources will be performed in the same workstation such that the precedence relations are not violated. In this work, an implementation of an elitist non-dominated sorting genetic algorithm (NSGA-II) is proposed to optimise ALBE-RC case study. An industrial case study was conducted in an electronic company and a product known as HM72A-10 series model has been selected for the case study. The results from the optimization shows that all the optimisation parameters i.e. number of workstations, cycle time and number of resources used could be minimised. The improvement of line efficiency also indicated that the optimization results are better that the existing one. The validation from industrial expert provides evidence that the proposed method is applicable and can be implemented for line balancing.

Keywords: Assembly Line Balancing, Type-E, Resource constraint, NSGA-II.

INTRODUCTION

An assembly line is one of manufacturing process comprises of a sequence of workstation in which a set of necessary task to assemble a product are performed. The aim of line balancing is to assign the tasks to an ordered sequence of workstations, such that the precedence relations are not violated and some performance measures are optimised (eg: maximise the line efficiency, minimise the number of workstations and minimise the cycle time). ALB is the decision problem of optimally partitioning the assembly tasks among the workstations related to some objectives [1]. Previous researchers make an assumption that any of assembly task can be performed and can be assigned to any workstation [2-5]. However, in reality each workstation has their own capabilities and specialization.

To the best of author knowledge, there is only a small number of research which consider resource constraint in ALB works [6-9]. Interestingly, none of them consider resource constraint in assembly line balancing type-e (ALB-E) problem itself. Most of previous researcher used traditional GAs as an optimization technique in ALB problem [10-12]. Yet, the implementation of NSGA-II in ALBE-RC has not been given great attention by the researchers [13]. In this work, assembly tasks that used the same resources i.e. machine, tool, and worker will be assigned in one workstation according to the precedence and cycle time constraint. Deb et al. introduced NSGA-II to accommodate a complex and real-world optimization problem for multi-objective function [14, 15]. Besides than incorporate elitism-preserving technique, NSGA-II also has the capabilities to find better solutions.

This paper presents an optimization of assembly line balancing type-E problem with resource constraint (ALBE-RC) on a selected industrial case study by using NSGA-II. The case study was conducted in an electronic company, which produced electronic components in Malaysia.

ELITIST NON-DOMINATED SORTING GENETIC ALGORITHM (NSGA-II)

Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) is an optimization algorithm developed by Deb et.al in the year of 2000. This algorithm was developed based on evolutionary algorithm, with modification in determining the leader in evolution process. Instead of having the best solution leader, the NSGA-II calculate the Crowding Distance to determine the leader [14-16].

NSGA-II procedure starts with initializing a random population P_i of size N_{pop}. The algorithm is then decoded into feasible sequences using topological sort. The fitness of feasible chromosomes is calculated by evaluate the objective functions. Later, a non-dominated sorting approach is applied to generate Pareto-optimal set. The entire population is sorted using non-dominated sorting approach to identify the non-dominated set $F = (F_1, F_2, \ldots, Fi)$. The parent population is filled with set F according to non-domination rank. If $F > N_{pop}$, the last front will be selected based on higher crowding distance (*CD)*. Since NSGA-II used the selection strategy based on crowding distance, it will gives an estimation of the density of selected solutions.

The tournament competition between two random-pair of solutions from parent population is performed to determine the domination rank. The population will be sorted in decreasing rank of level according to each objective function. Solution with better rank is filled in parent pool. Meanwhile, the solution with the same rank but remains in a less crowded area will be selected. The tournament selection is repeated until the parent pool is fully occupied to generate children. New offspring population Q_i of size N_{pop} is generated from P_i by crossover and mutation operators. Later, P_i and Q_i are combined to form new population R_i of size $2N_{pop}$. The NSGA-II procedure is repeated until the termination criteria is met.

As mentioned previously, the aforementioned algorithm implements an elitism-preserving technique. It will ensures that the best solution found in each generation will never be lost until the better solution is discovered [17-19]. The flowchart of NSGA-II is illustrated in Fig. 1.

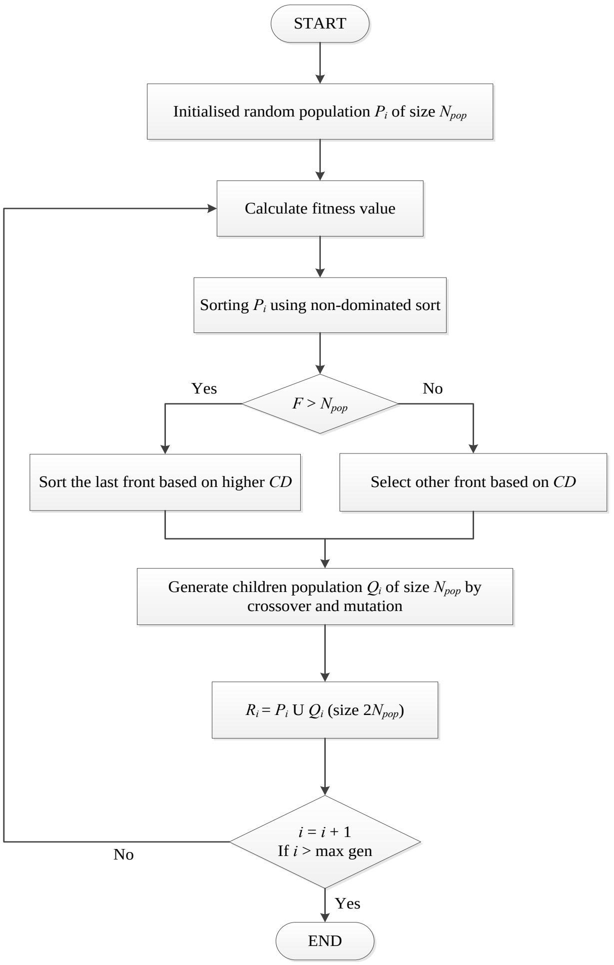

Figure 1. Flowchart of NSGA-II

INDUSTRIAL CASE STUDY

A. Product and Company Background

TT Electronics is a United Kingdom based manufacturer that produces sensing and control for industrial and car makers, advanced components and integrated manufacturing services (IMS). The advanced components provide engineered components solutions such as resistors, power and hybrid devices, magnetics and connectors. The magnetics components are handled by BI Technologies Corporation Sdn. Bhd. that was located in Kuantan, Malaysia. BI Technologies Corporation is wholly owned subsidiary by TT Electronics. Their product design team are focused on custom and semi-custom product based on customers' needs. The products that have been produce by the company are magnetic components, power and signal, inductors SMD (Surface Mount Device) and through hole, molded inductor, and lamination transformer.

For this case study the moulded inductor production section is selected as the product running on the line is a type of single model. Only HM72A-10 series model was running on the line during the data collection. HM72A-10 series is a type of moulded inductor. This class of product is a high power low cost moulded SMD inductor which is typically used in electronic device such as computer. Table I presents the summary of the production line of HM72A-10 series model. A total of 13 workers were assigned in all workstations to perform all the tasks with a number of 30 machines and tools that had been used throughout the process.

Table I: SUMMARY ON HM72A-10 PRODUCTION

Work element		**ST**	**Resources (machine, tool and worker)**		**pt (s)**
a_1	Aircoil winding	ST1	Auto CNC Aircoil Machine	W1	5.1
a_2	Aircoil leadout flatenning	ST2	Pneumatic press 1	W2	7.8
a_3	Aircoil leadout trimming	ST3	Pneumatic press 2	W3	6.1
a_4	Aircoil leadout stripping (upper side)	ST4	Stripping machine 1	W4	8.3
a_5	Aircoil leadout side stripping (lower side)	ST4	Stripping machine 2	W5	7.8
a_6	Leads dip soldering	ST5	Solder pot Tweezer Flux	W6	4.5
a_7	Flux cleaning	ST6	Dish washer	W6	0.8
a_8	Aircoil leadout forming	ST7	Pneumatic Forming Machine	W7	4.4
a_9	Rod core assembly to aircoil	ST8	Bent tip tweezer Varnish container	W8	4.6
a_{10}	Rod curing	ST9	Oven Baking tray	W8	4.0
a_{11}	Moulding press	ST10	Double acting compression moulding	W9	8.1
a_{12}	Inductor clamping	ST11	Tongs Clamping machine	W10	3.2

Work element		ST	Resources (machine, tool and worker)		pt (s)
a_{13}	Unit curing	ST12	Oven Baking trolley PC profiler	W10	9.0
a_{14}	Unit unclamping from tongs	ST13	Tongs Clamping machine	W10	1.6
a_{15}	Lead cropping and forming	ST14	Semi-auto crop & form machine	W11	4.7
a_{16}	Part number marking	ST15	Video jet printer	W12	2.2
a_{17}	IR-reflow	ST16	IR-Reflow machine Baking tray	W12	2.3
a_{18}	VMI, Inductor/DCR + Q-factor	ST17	Mantis scope Height Gauge LCR meter	W13	6.4
a_{19}	Packaging	ST17	Tape & reel machine	W13	1.5

Indicator: ST = Workstation, W = Worker, pt = processing time

B. Results and Discussion

An industrial data collection for a selected product which is HM72A-10 series model has been conducted to collect the necessary data such as precedence relations, tasks time and resources used. The current layout of the selected product consist of 19 tasks that were assigned to 17 workstations with a total of 48 resources were used. A simulation of existing layout had been conducted using Witness™ software to simulate the assembly line. Witness™ is a simulation software that commercially used to provide overall view on all the process in terms of busy, idle, blocked and output. The purpose of existing layout simulation is to validate the simulation model with actual layout.

Table II shows the proposed task assignment. It clarifies the details on what task has been assigned in each workstation and their respective total processing time. However after the validation stage, the industrial expert decided that task a_1 (aircoil winding) and task a_2 (aircoil leadout flattening) cannot be assigned in one workstation. Yet, it should be in two different workstations. The highest processing time recorded in Table 2 is 13.1 seconds which is in workstation 4 (ST4).

Table II. PROPOSED TASK ASSIGNMENT

ST	**Task**	**Resources**	**Total processing time (s)**
ST1	a_1 – aircoil winding	W1, W2 Auto CNC aircoil machine Pneumatic press 1	12.9
	a_2 – aircoil leadout flattening		
ST2	a_3 – aircoil leadout trimming	W3 Pneumatic press 2	6.1
ST3	a_4 – aircoil leadout stripping	W4 Stripping machine 1	8.3
WS	**Task**	**Resources**	**Total processing time (s)**
ST4	a_5 - aircoil leadout side stripping	W5 Stripping machine 2 Solder pot Tweezer Flux Dish washer	13.1
	a_6 – leads dip soldering		
	a_7 – flux cleaning		
ST5	a_8 – aircoil leadout forming	W6 Pneumatic forming machine Bent tip tweezer Varnish container Oven Baking tray	13.0
	a_9 – rod core assembly to aircoil		
	a_{10} – rod curing		
ST6	a_{11} – moulding press	W7 Double acting compression moulding Tong Clamping machine	11.3
	a_{12} – inductor clamping		
ST7	a_{13} – unit curing	W8 Oven Baking tray PC profiler	10.6
	a_{14} - unit unclamping from tongs		
ST8	a_{15} – lead cropping and forming	W9 Semi auto cropping and forming machine Video jet printer IR-reflow machine Baking tray	9.2
	a_{16} – part number marking		
	a_{17} – IR-reflow		
ST9	a_{18} – VMI, inductor/DCR + Q-factor	W10 Mantis scope Height gauge LCR meter Tape and reel machine	7.9
	a_{19} - Packaging		

Table III indicates the task assignment after have been validated. The table clearly shows that aircoil winding (a1) and aircoil leadout flattening (a2) are individually assigned in workstation 1 and workstation 2. Therefore, the number of workstation has been increased from 9 workstations to 10 workstations after the validation. The highest processing time is remained unchanged which is 13.1 seconds meanwhile, the lowest processing time is 5.1 seconds.

Table III. TASK ASSIGNMENT AFTER VALIDATION

ST	Task	Resources	Total processing time (s)
ST1	a_1 – aircoil winding	W1 Auto CNC aircoil machine	5.1
ST2	a_2 – aircoil leadout flattening	W2 Pneumatic press 1	7.8
ST3	a_3 – aircoil leadout trimming	W3 Pneumatic press 2	6.1
ST4	a_4 – aircoil leadout stripping (upper side)	W4 Stripping machine 1	8.3
ST5	a_5 - aircoil leadout side stripping (lower side)	- W5 - Stripping machine 2 - Solder pot - Tweezer - Flux - Dish washer	13.1
	a_6 – leads dip soldering		
	a_7 – flux cleaning		
ST6	a_8 – aircoil leadout forming	- W6 - Pneumatic forming machine - Bent tip tweezer - Varnish container - Oven - Baking tray	13.0
	a_9 – rod core assembly to aircoil		
	a_{10} – rod curing		
ST7	a_{11} – moulding press	-W7 - Double acting compression moulding - Tong - Clamping machine	11.3
	a_{12} – inductor clamping		
ST8	a_{13} – unit curing	-W8 - Oven - Baking tray - PC profiler	10.6
	a_{14} - unit unclamping from tongs		
ST9	a_{15} – lead cropping and forming	-W9 - Semi auto cropping and forming machine - Video jet printer - IR-reflow machine - Baking tray	9.2
	a_{16} – part number marking		
	a_{17} – IR-reflow		
ST10	a_{18} – VMI, inductor/DCR + Q-factor	-W10 - Mantis scope - Height gauge - LCR meter - Tape and reel machine	7.9
	a_{19} – Packaging		

Table IV shows the simulation results of existing layout, after optimization using NSGA-II and the result after validation. The validation is conducted by an interview and discussion session to determine either the optimization result using the proposed method is acceptable or not. For the validation purpose, some queries has been raised during the interview and discussion session; (i) Do the proposed layout is possible to be implemented in the production line? (ii) Do the effectiveness of the line achieved the industrial target?

The most striking observation to emerge from the results of comparison was the number of workstations are extensively decreased after the NSGA-II optimization from 17 workstations that were used for the existing layout to 9 workstations. The rapid decrease in the number of workstation is because of all the tasks that used same type of resources will be assigned to one workstation subject to the constraints i.e. (i) the precedence relations are not violated (ii) total processing time in each workstation does not exceed the cycle time.

However, the number of workstations has been increased to 10 after the validation. This is due to some of the tasks cannot be assigned to the same workstation. This situation caused the value of busy percentage in workstation after the validation turn out to be less (70.5%) compared with after the optimisation (78.3%). However, both values remain lower compare to the busy percent of workstation of the existing layout which is 33.7%. In fact, the number of resources being used also show a reduction of 3 resources both after the optimization and validation.

The efficiency of the line is calculated using (1) as follows:

$$E = \frac{\sum_{i=1}^{m} T_i}{mc} \times 100\% \qquad (1)$$

where E: Line efficiency

m: Number of workstation

c: Cycle time

T_i: Total processing time of the i^{th} workstation

The simulation results indicates that the line efficiency of the existing layout is the worst among the three results i.e. existing layout, 33.8%; after optimization, 78.4%; after validation, 70.5%. This can be concluded that the most efficient line was after the optimization. Meanwhile, the percentage value of blocked in workstation is the lowest after the optimization (9.7%), compared to the result after the validation and existing layout which is 18.8% and 10.5% correspondingly. Besides, the results show that the percentage busy of worker after the optimization is the same as after the validation which is 70.5%. This is due to the reason of the number of worker assigned to all workstations in the both phases are the same. The idle percentage of worker for both stages are also comparable which is 29.5%.

Table IV. COMPARISON OF EXISTING, NSGA-II OPTIMIZATION AND VALIDATION RESULTS

Data	Existing	After NSGA-II optimization	After validation
NWS	17	9	10
CT	16.1	13.1	13.1
Resource	43	40	40
% Line eff.	33.8	78.4	70.5
%Busy (Workstation)	33.7	78.3	70.5
%Idle (Workstation)	55.7	12.0	10.7
%Blocked (Workstation)	10.5	9.7	18.8
%Busy (Worker)	44.1	70.5	70.5
%Idle (Worker)	55.9	29.5	29.5
Daily output	4914	6039	6039

In the meantime, the existing layout shows the worst reading for busy percentage of worker (44.1%) and also the percentage of idle of worker (55.9%). The results obtained from the NGSA-II optimization shows that the proposed method can be implemented in manufacturing industry for the target to enhance the industrial productivity as well as increase the line efficiency. The validation from industrial expert concluded that the proposed layout was a worthy plan as it can minimise the number of resources used and number of workstations. On top of that, the efficiency and the productivity of the line also can be increased.

As we can see from Table IV, the daily output obtained from the existing layout is 4914 units, while the output achieved after both the optimisation and validation is 6039 units per day. Apart from the optimisation parameters, the output of the production was increased as well. Thus, the proposed method and the optimisation algorithm are applicable for industrial application.

CONCLUSION

This paper presents a case study to optimize assembly line balancing type-e problem with resource constraint (ALBE-RC) by using elitist non-dominated sorting genetic algorithm (NSGA-II). The finding from the industrial case study provides evidence that the results of optimization have improvement in term of line efficiency, daily output, number of workstations, cycle time and also the usage of resources compared with the existing layout. The validation from the industrial expert also shows that the proposed method is applicable and can be implemented for industrial application.

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