A Determination of Optimal Work-piece Feed Rate on Double Spray Booths to an Oven

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***Abstract*—One of the important processes in cookware manufacturing is a coating process where coating material is sprayed to cover an interior and/or exterior surfaces of a product. Then, the wet coated product must be baked in the oven at a certain temperature profile to dry the wet coated surface. Normally, the spray and baking processes are continuously connected and loading should be balanced. Due to the fact that coating process is faster than that of baking process. Thus, double spray booths are designed to feed the oven. However, if the feeding rate is not optimized, the oven capacity tends not to be fully utilized. This is due to the fact that cookware product is designed in different sizes and shape. The mixed work-pieces are simultaneously coated and baked. Therefore, a feeding pattern and optimal feed rate must be determined to match with oven capacity in order to maximize its capacity. Thus, the objective of this paper is to reveal detailed calculation and its result to achieve this goal and it can be an example for other similar applications.**

***Index Terms*—Feed rate, optimization, oven capacity, spray coating**

I. Introduction

Cookware and kitchenware industry has been growing up and playing an important role in human daily life due to the fact that cookware products are an essential tool for cooking activity. Thus, a leading cookware manufacture must increase a production, quality, feature, delivery, etc. for responding to consumers [1-2]. The manufacturing of cookware products involve blanking, stamping, deep drawing, polishing, coating and so on. The productivity improvement is of interest to the manufacturer as much as defect and rework. Although, there are several processes in the production, coating is the most time consuming process due to lengthy baking cycle time. As mentioned earlier, spray coating process and baking process is continuous [3]. That is, as soon as a product is coated by a spray process, it will immediately transfer to the oven which is next to the spray booth. Typically, the cookware product size ranges from 10-50 cm whereas the oven conveyor width is around 200-250 cm so the conveyor width is much larger than of the pans. Therefore, the oven can accommodate more than one pan at a time depending upon the size of the pan being loaded to the oven. Thus, one oven is designed to serve two spray booths simultaneously as shown in Fig. 1. In current, speed of spray booths are set by technicians or leaders. They can't set optimal spray booths speed for maximize feed rate and use maximize oven utilization all times because they didn't have standard times to setting and it isn't easy to find. They will use skill and experience for setting speed of spray booths and depends on the jobs and oven loading. The complication of products that have many sizes and oven must serve two spray booths that oven need to share oven area. It is hard to decision to choosing pan to produce on each spray booths and setting optimal speed within short time [8]. Typically, the size of a products being loaded to the oven can be calculated and known in advance; therefore, in order to balance between spray booths and the oven, feed rate of the spray booth must be calculated and used to adjust the spray booth speed [4-7]. Thus, spray booth speed depends upon part feed rate to the oven and other constrains such as maximum conveyor speed, spray time, and so on. In addition, speed conveyor oven can a little adjust only because it related with oven temperature and oven have to open all times for controlling temperature what going temperature down. These costs and constraints of oven area are important that have to be fully oven utilization.

Therefore, the aim of paper is to calculate optimal part feed rate and then a spray cycle time so that the available area of the oven conveyor is fully utilized based on one and two spray booth usage with mathematical model by solver function in Microsoft Excel [9]. The software Excel Solver is illustrate for solution of nonlinear equations or nonlinear programming problems, problems with multiple criteria and complex features that person can't calculate or hard to decision by yourself. However, it gives optimization answers and fast to calculation [10-22].

II. Mathematical Model

Due to the fact that there are various shape and size of pots and pans for coating, a combination of them must be defined in order to maximize oven utilization. Thus, the mathematical is formulated to obtain the optimal solution together with the loading feed rate from a spray booth to the oven conveyor under several working constraints. The mathematical model is consisted of the objective function and constraints which will describe next.

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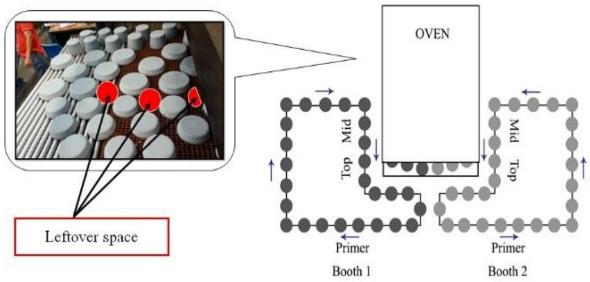


Figure 1. Oven and spray booth configuration.

Since the spray booth is designed as a conveyor line where a work-piece is positioned consecutively on a fixture attached on the spray conveyor and then flows through a spray robot for interior or exterior coating. Thus, a conveyor speed will be related to feed rate of the part to the oven conveyor as one can see that two spray lines are positioned next to the oven as shown in Fig. 1. Once the coating is completed, a pan must be immediately loaded to the oven conveyor for curing. Note that, the maximum of two pans per spray booth can be loaded to the oven at a time. Thus, if two spray booths are used, the maximum of four pans can be loaded at a time. Thus, let define index as follows:

A. Index and Parameter

i = Position of a pan on the spray conveyor where i = 1, 2, … I

Note that 1 and 2 is the position on the conveyor spray booth I whereas 3and 4 is the position on the conveyor spray booth II.

j = Type of pan body where j = 1, 2, …, J
D_{ij} = Area of pan of j at position i (mm^2)
A = Available area of oven conveyor (mm^2)
P_{max}= Maximum allowable feed rate (pc/min)

B. Decision Variable

x_{ij} = 1 if pan j is mounted at position i
= 0 Otherwise
y_i = Feed rate of position i (pc/min)

C. Objective Function

The mathematical model so-called optimization model is consisted of the objective function and a bunch of linear constraints. The objective function is aimed typically either to minimize or to maximize a decision variable (s) where is a variable that we can control or decide a value to satisfy the goal. The linear inequality constraints provide a solution boundary which restricts a feasible solution to the problem. In this case study, the objective function is to maximize used area of the oven conveyor. That is, pots and pans must be placed on the oven conveyor so that the oven conveyor area is fully utilized. Therefore, a multiplication of pan areas to number of pans fed per minute or feed rate will be a total area of pan occupied on the oven conveyor per minute. Thus, the objective function will be:

$$\text{Max } Z = \textstyle\sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij} x_{ij} y_i \tag{1}$$

The objective function is subjected to constraints as follows:

1) Area constraint. The maximum occupied area by pots and pans is constrained by the available area of the oven.

$$\textstyle\sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij} x_{ij} y_i \quad \leq \quad A \tag{2}$$

2) Position constraint. This constraint ensures that only one pan model can occupy at only one position i of the spray conveyor.

$$\textstyle\sum_{j=1}^{J} x_{ij} \quad = \quad 1 \qquad \forall i \tag{3}$$

3) Feed rate constraint. This constrain ensures that the feed rate should range between one and Pmax (pcs/min). In other words, the feed rate must not be too fast to load by an operator.

$$1 \leq y_i \leq P_{max} \qquad \forall i \tag{4}$$

4) Technological constraint. This constraint ensures that position 1 and 2 at the spray booth I moves at the same speed as shown in (5) and so do the position 3 and 4 at the spray booth II as shown in (6).

$$y_1 \quad = \quad y_2 \tag{5}$$

$$y_3 \quad = \quad y_4 \tag{6}$$

5) Binary constraint. The value of xij can be only either zero or one.

$$x_{ij} \in 0, 1 \qquad \forall i, \forall j \tag{7}$$

6) Integral constraint. The value of yi is nonnegativity integer.

$$y_i \in 0, \text{integer} \qquad \forall i \tag{8}$$

III. IMPLEMENTATION

TABLE I. SPECIFICATION OF TESTED BODIES

Body	**QAL14IA**	**QAL18LH**	**QAL24LH**	**SQZ28**	**EAU20IA**	**TBN16LA**
Pan diameter (mm)	156	196	256	295	216	173
Gap (mm)	30	30	30	30	30	30
Pan area (mm^2)	24,366	38,446	65,566	87,055	46,686	29,959

In order to verify the developed mathematical model, six different sizes of pans are selected as a candidate for coating. Detailed specifications of pan bodies, such as pan diameter, clearance (gap) and area are tabulated in Table I. It should be noted that the each wet coated pan must not contact each other; therefore the imaginary square shape surrounded the pan will be used for area calculation. Thus, the calculated area is a product of width and height. Note that both width and height must add gap clearance on both sides.

The oven conveyor dimension is 1759 mm wide and it moves at the speed of 1098 mm/min. Two spray booths are employed to perform coating operation. The loading pattern will be an in-line pattern as shown in Fig. 2. which positions placing work-piece onto oven 1 and 2 are positions pans/pots for spray booth I and positions placing work-piece onto oven 3 and 4 are positions pans/pots for spray booth II. It should be noted that a typical loading time of a pan onto the oven conveyor depends upon size of a pan and must has clearance (gap) between work-piece 30 mm as show in Fig. 3. Pans are transferred from the spray conveyor to oven conveyor have maximum cycle time around 4 sec. which product size range 10-20 cm have maximum number of loadable-pans (P_{max}) 17 pcs/min. and product size range 21-40 cm have maximum number of loadable-pans (P_{max}) 15 pcs/min.

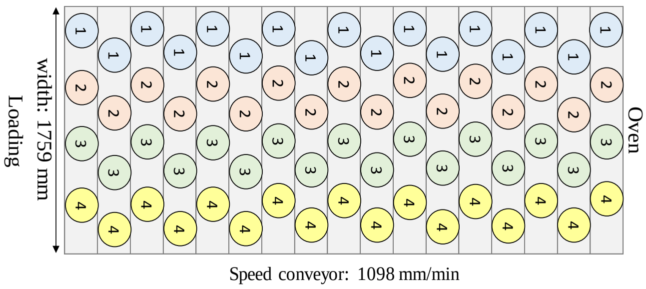


Figure 2. Loading pattern on the oven conveyor.

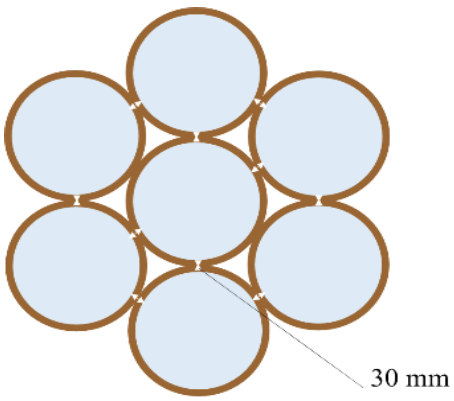
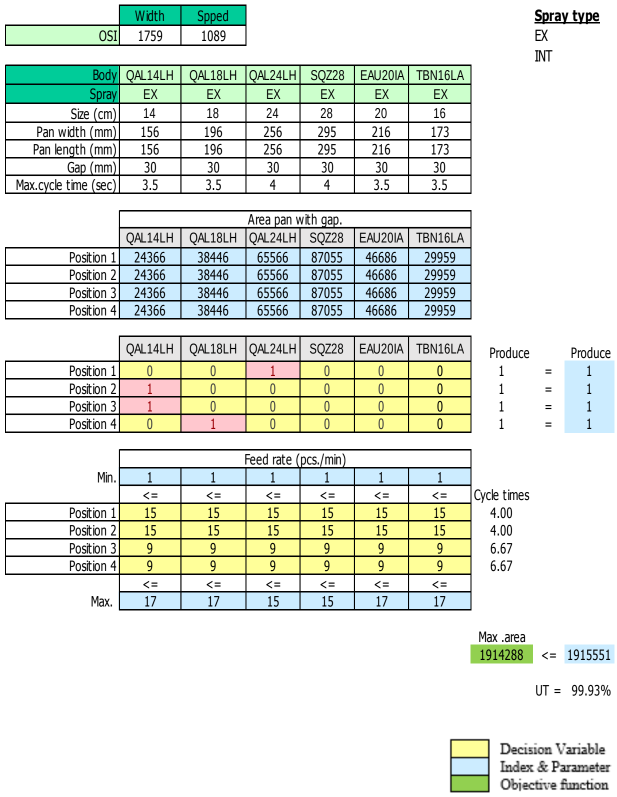


Figure 3. Clearance (gap) loading pattern.

IV. Result

The software Excel Solver is utilized to determine the optimal solution for this case study as show in Fig. 4. that The software Excel Solver will choose products are produce (if product are choose, it will show 1 but if not choose to produce, it will show 0) and tell optimal feed rate for each products. The solution is summarized in Table II where QAL24LH and QAL14LH is selected to spray on booth I at positions 1 and 2. QAL14LH and QAL18LH will be coated on spray booth II at position 3 and 4 respectively. Feed rate of spray booth I is 15 piece per minute while that of spray booth II is 9 piece per minute. The cycle time and area utilization on the oven conveyor is tabulated in Table III.



	Width	Spped
OSI	1759	1089

Spray type
EX
INT

Body	QAL14LH	QAL18LH	QAL24LH	SQZ28	EAU20IA	TBN16LA
Spray	EX	EX	EX	EX	EX	EX
Size (cm)	14	18	24	28	20	16
Pan width (mm)	156	196	256	295	216	173
Pan length (mm)	156	196	256	295	216	173
Gap (mm)	30	30	30	30	30	30
Max.cycle time (sec)	3.5	3.5	4	4	3.5	3.5

	Area pan with gap.					
	QAL14LH	QAL18LH	QAL24LH	SQZ28	EAU20IA	TBN16LA
Position 1	24366	38446	65566	87055	46686	29959
Position 2	24366	38446	65566	87055	46686	29959
Position 3	24366	38446	65566	87055	46686	29959
Position 4	24366	38446	65566	87055	46686	29959

	QAL14LH	QAL18LH	QAL24LH	SQZ28	EAU20IA	TBN16LA	Produce		Produce
Position 1	0	0	1	0	0	0	1	=	1
Position 2	1	0	0	0	0	0	1	=	1
Position 3	1	0	0	0	0	0	1	=	1
Position 4	0	1	0	0	0	0	1	=	1

	Feed rate (pcs./min)						
Min.	1	1	1	1	1	1	
	<=	<=	<=	<=	<=	<=	Cycle times
Position 1	15	15	15	15	15	15	4.00
Position 2	15	15	15	15	15	15	4.00
Position 3	9	9	9	9	9	9	6.67
Position 4	9	9	9	9	9	9	6.67
	<=	<=	<=	<=	<=	<=	
Max.	17	17	15	15	17	17	

Max .area
1914288 <= 1915551

UT = 99.93%

Decision Variable
Index & Parameter
Objective function

Figure 4. The Optimal by the software Excel Solver.

TABLE II. Summary of Result Obtained from Excel Solver

Decision Variable	Booth I		Booth II	
	Position 1	Position 2	Position 3	Position 4
x_{ij}	QAL24LH	QAL14LH	QAL14LH	QAL18LH
y_i	15	15	9	9

TABLE III. Resulted Cycle Time and Utilization

Details	Booth I		Booth II	
	Position 1	Position 2	Position 3	Position 4
	QAL24LH	QAL14LH	QAL14LH	QAL18LH
Cycle time (sec)	4	4	6.67	6.67
Utilization of oven (%)	99.93			

From the solution obtained from the developed mathematical model. The optimal feed rate of spray booth I is 15 pieces per minute; therefore, the cycle time can be calculated at 4 sec whereas the optimal feed rate at spray booth II is 9 pieces per minute and the calculated cycle time is 6.67 sec. The oven conveyor utilization is 99.93

percent. Meaning that the oven conveyor is fully used up by loading QAL24LH and one piece QAL14LH at spray booth I with 15 pc/min feed rate while one piece of QAL14LH and one piece of QAL18LH at spray booth II with 9 pc/min feed rate. As a result, the production output will be 2,880 pieces per hour.

V. Discussion

In coating application, a work-piece must be baked after coating for better quality. The oven is normally a slow process due to temperature profile. Thus, in order to maximize productivity, the oven area must be fully utilized. Practically, in a mixed model production, there are a number of products simultaneously available for production. Planning to produce will plan by using skill and experience of technicians or leaders of process only because process don't have standard times. Planning of a product (s) to be on the spray booth for coating is not an easy task and the result is not always optimized decision. Thus, this paper formulated the mathematical model in order to determine optimal spray booth speed or determine the optimal feed rate and also select a product on each spray booth position so that when they are loaded to the oven conveyor, the area of the oven is fully utilized.

The unique of this model is a capability of calculating optimal feed rate related to the coating products with an aim at maximizing an oven which is considered worthwhile and can be used for automated conveyor adjustment. This mathematical model obtained from the research has been tested to many cases. It is found that the developed model is considered practical and can increase productivity. This solves the bottle-neck problem of coating or spray of a small work-piece which subsequently baked in the oven.

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