Cycle Time Improvement for Fuji IP2 Pick-and-Place Machines

Some of the major enhancements are eliminating head contention, reducing or eliminating nozzle changes, supporting user-defined nozzles, supporting large nozzles for holders 2 and 3, and being able to define multiple part data for a given part number. The cycle time improvement exceeds the original goal of 5%, and the result at one surface mount center was more than 16% over hand-created and optimized recipes. The solution helps both the high-volume and the high-mix centers.

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Reduction of placement cycle time in an assembly line is one of the major goals in a surface mount shop. It is more important in a high-volume shop than in a high-mix shop because most of the assembly time is spent in part placement. The reduction of placement cycle time at high-volume centers would have a higher impact than at our high-mix centers.

HP owns many Fuji IP2 machines at our surface mount centers, one on each line. The Fuji IP2 machine is a fine-pitch pick-and-place machine capable of placing parts from reel, stick, and waffle feeders. It is considered a general-purpose pick-and-place machine because of its ability to place a wide range of parts. It has two heads, which alternately pick up parts from the feeders and place them on the panel. Each head has two holders, one with a fixed nozzle and one with an automatic nozzle. A fixed nozzle must be installed into the fixed holder before the machine starts placing parts. An automatic nozzle of size S, M, L, or LL can be picked up by the automatic holder from a nozzle station. The nozzle station has six nozzles: one S nozzle, one M nozzle, two L nozzles, and two LL nozzles. The S and M nozzles are shared between the two automatic holders of the two heads. Each automatic holder has its own L and LL nozzles; they are not shared between the two automatic holders.

Since the S and M nozzles are shared between the two automatic holders, it is important that the sequence of placement be arranged so that the two automatic holders do not require the S or M nozzle at the same time. If they do, depending on the particular Fuji IP2's firmware, either one side will halt until the other side finishes its placement and releases the nozzle, or the IP2 software will crash. In either case, head contention is created, which is a problem for IP2 placement machines.

The Fuji IP2 machine has slot numbers 1 through 37, 51 through 87, and 101 through 110. Slots 101 through 110 are used by the waffle unit. If the waffle unit is installed, it interferes with the machine and makes slots 1 through 3 inaccessible. Slots 1 to 37 and 51 to 87 can be used for mounting either reel feeders or stick feeders. Slots 101 to 110 are used for waffle feeders.

The IP2 machine has a number of of constraints. Only one of the automatic holders (holder 1) can access waffle parts from slots 101 to 110. This holder can also access slots 4 to 37 if a waffle unit is installed or slots 1 to 37 if no waffle unit is installed. The other automatic holder (holder 4) can access slots 51 to 87. One of the fixed holders (holder 2) can access slots 4 to 37 (not 1 to 37) and the other fixed holder (holder 3) can access slots 51 to 84 (not 51 to 87). The two fixed holders 2 and 3 can pick up parts up to 3.5 mm in height and the two automatic holders can pick up parts up to 10 mm in height.

Fig. 1. *Fuji IP2 pick-and-place machine layout.*
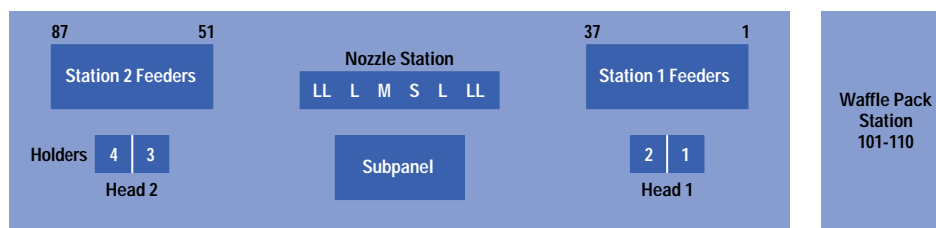
The Problem

The issues related to the Fuji IP2 are in two categories. One category consists of the issues that reduce the placement cycle time, such as use of the next device, use of multiple part data, the ability to assign a part to both sides, and the ability to assign placements to holders based on reference designators. The other category consists of the issues that make the

machine perform correctly. The main item in this category is head contention. If head contention occurs, for certain IP2 firmware the machine halts and the user must change the sequence of the recipe to run the machine again.

The Methods

In this section, we describe our solution for each issue related to the Fuji IP2 machine. This includes elimination of head contention, support of the next device mechanism of the IP2, support for user-defined nozzles such as a modified medium nozzle for holders 2 and 3, use of multiple part data for a part number, and assignment of a part to both sides of the machine to achieve a better head balance.

Our general solution is as follows: we assign placements to holders to balance the load among the four holders. In the process, we consider first the placements that have slots already assigned. This is the case when the part numbers are in the input setups. Then we assign slots to those placements that do not have slots in the input setup. This general solution is used for both setup and sequence modules. In the sequence module, all the placements have their slots assigned.

In the following sections, we describe many issues which are considered when assigning placements to holders. Our solutions have been incorporated in setup and sequence generation modules for the Man-Link recipe generation system, which is used by all HP surface mount centers that have Fuji IP2 machines. Other Man-Link enhancements are discussed in *Article 9*.

Eliminating Head Contention. Head contention occurs when holders 1 and 4 need the same nozzle (S or M) at the same time. At this time, the machine behaves differently depending on what firmware it has. Machines having older versions will stop and the user must edit the recipe to eliminate the head contention. In newer versions, the holder that needs the S or M nozzle must wait until the other holder finishes its placements and releases the S or M nozzle.

In our solution, we do not assign parts requiring the S or the M nozzle to both holders 1 and 4. We assign each nozzle only to one of them, depending on the loads of the holders. This way, the machine in the worst case will place all such parts with one side. This would not be worse than the case in which one side must wait until the other side finishes.

As an example, assume that there are two parts, each requiring the M nozzle and each having 10 placements. Further assume that holders 2 and 3 do not have any nozzles attached to them. Assigning both of these parts to one side, say to holder 1, would not be worse than the case in which one part is assigned to holder 1 and the other part is assigned to holder 4. Using our solution, Man-Link assigns both parts to one side, say holder 1. In this case, the machine will go back and forth and place one part at a time for total of 20 round trips. If one part is assigned to holder 1 and the other is assigned to holder 4, and if the machine has the latest firmware, holder 1 will pick up the M nozzle and go back and forth and make its 10 placements. While holder 1 is placing parts, holder 4 must wait until holder 1 releases and replaces the M nozzle. At that time, holder 4 will pick up the M nozzle and go and make its 10 placements. The machine has to do two nozzle changes for each board, both of which are unnecessary. Our solution does not need any nozzle changes in this particular case, thereby saving 10 to 15 seconds.

Our solution not only eliminates the head contention, but has the additional benefit of eliminating nozzle changes because of head contention. In the past, users would not assign to the IP2 parts requiring S or M nozzles because of the head contention issue. This caused the IP2 to be underutilized. Now users can assign such parts to the IP2 when necessary and this will help to reduce the overall cycle time of products being built.

Using Slot Link (Next Device). With Fuji IP2 machines it is possible to place multiple feeders containing the same part on the machine and have the recipe reference one of the slots. When the parts from that slot are depleted, the machine goes automatically to the next slot that has that part and continues placing.

This slot link mechanism is very helpful for waffle parts. Since the waffle feeders do not take many parts, the operator frequently has to stop the machine and replenish the parts. If a recipe uses only one fine-pitch part from the waffle unit, all 10 waffle feeders of the IP2 can be filled at once and all of these parts can be used before the machine needs to be stopped to refill that part.

The mechanism provided by Man-Link is as follows. The user enters, in an input setup, the slots that a particular part is to occupy and then Man-Link takes over and creates the recipe appropriately. As an example, if a part is assigned to all 10 slots of the waffle pack unit, we would have a recipe containing the slots and slot links (next devices) shown in Table I.

As shown in Table I, a circular link is created between slots 101 through 110. The next slot for slot 101 is 102, the next slot for slot 102 is 103, and so on. The last slot, slot 110, is linked to slot 101, the first slot, to create a circular link. The operator will fill all ten trays with part 1. In the recipe for this part, slot 101 is referenced. The machine starts picking up parts from slot 101 and places them on the board until all parts are used up. Then the machine will go to the next slot, which is slot 102, and start placing parts. This will continue until parts from all ten feeders are depleted. Then the machine will stop, the operator will fill all ten trays, and the cycle will begin again.

Table I
Slot Link (Next Device) Example

Part Number	Slot (Device)	Slot Link (Next Device)
Part 1	101	102
Part 1	102	103
Part 1	103	104
Part 1	104	105
Part 1	105	106
Part 1	106	107
Part 1	107	108
Part 1	108	109
Part 1	109	110
Part 1	110	101

User-Defined Nozzles. Holders 2 and 3 take a fixed nozzle. The nozzle sizes that Fuji supplies for these two holders are S and M. One of our surface mount sites created a larger nozzle for these two holders. This expanded the capability of the machine so that it can pick up as many as four larger parts, while the original machine can pick up only two larger parts. Although the nozzles are larger, the Fuji machines require that these nozzles still be called S or M in recipes. Another issue is that these larger S and M nozzles must be distinguished from the S and M nozzles that holders 1 and 4 can pick up from the nozzle station. For these reasons, we provide a mechanism that allows the user to define any name for a particular nozzle and then map it to one of the Fuji-recognized nozzles (S, M, L, LL).

Our mechanism is as follows. The user defines what nozzles are installed in the nozzle station on the machine and what nozzles are installed in the two fixed holders. The names of the nozzles are user-defined. We have provided six configuration parameters to name the six nozzles in the nozzle station and two configuration parameters to name the two fixed nozzles, as shown in Table II.

Table II
Configuration Parameters to Name the IP2 Nozzles

Configuration Parameter	Description	Possible User-Defined Nozzle Names
LEFT_LL_NOZZLE	The left LL nozzle in the nozzle station	LL, ML, XL
LEFT_L_NOZZLE	The left L nozzle in the nozzle station	L
M_NOZZLE	The M nozzle in the nozzle station	M
S_NOZZLE	The S nozzle in the nozzle station	S
RIGHT_L_NOZZLE	The right L nozzle in the nozzle station	L
RIGHT_LL_NOZZLE	The right LL nozzle in the nozzle station	LL, ML, XL
HOLDER2_NOZZLE	The nozzle in fixed holder number 2	S, M, Modified Medium
HOLDER3_NOZZLE	The nozzle in fixed holder number 3	S, M, Modified Medium

In Man-Link, a part number is linked to Fuji part data. In the part data, the user defines a nozzle (like Modified Medium) and then links this nozzle to a Fuji nozzle, which might be M. We use the user-defined nozzles of each part to assign them to nozzles of the machine, which are also specified by the user.

In Table III, the actual dimensions of the different nozzles used at different HP surface mount sites are listed.

Multiple Part Data for a Part. From the discussion of the previous section, it is obvious that a part might be picked up successfully by multiple nozzles. For example, a part might be picked up by both Modified Medium and ML nozzles. Their nozzle diameters are very close: 6 mm and 7 mm, respectively. For this reason, we have provided part data preferences such that the user can decide which part data (and in turn which nozzle) is the best for picking up a part, and give it the highest

preference. The user can then provide additional part data, using other nozzles sizes, for that part with lower preferences. Our software will try to use the part data with the highest preference, but it will use other part data if it will improve the balance among the four holders.

Table III
Nozzle Sizes Used at HP Surface Mount Centers

User-Defined Nozzle Name	Fuji Nozzle Name	Holders	Nozzle Diameter (mm)	Light Ring Diameter (mm)
SS	S	1,2,3,4	1.0	21
S	S	1,2,3,4	1.3	21
M	M	1,2,3,4	2.5	33
Modified Medium	M	2,3	6.0	33
L	L	1,4	4.0	71
ML	LL	1,4	7.0	71
LL	LL	1,4	10.0	71
XL	LL	1,4	15.0	91

A user who has multiple part data defined in the system might still want to use the part data with the highest preference. We have provided the configuration parameter MULTI_PART_DATA with values of YES and NO so the user can choose whether all part data for a part should be considered or just the part data with the highest preference.

Assigning a Part Number to Both Sides of a Machine. Occasionally a product will have a part number that constitutes more than 50% of all the placements for the IP2. We have seen cases in which there is only one part assigned to the IP2. If only one part is assigned to the machine, one of the heads will be busy placing parts while the other head is idle, doing nothing. For this reason, Man-Link allows the user to duplicate the part on both sides of the machine and the software will split the reference designators of that part between the two heads to balance the load.

If a machine is used in a high-volume shop for such cases, multiple feeders of the dominant part can be placed on each side of the machine to take advantage of the splitting of the reference designators described in this section and the slot link (next device) feature described earlier.

Assigning Placements to Holders by Reference Designators. Assume that there is only one part assigned to an IP2 for a product and it is placed on the right side of the machine, where holders 1 and 2 are located. Further assume that the part requires an S nozzle, and an S nozzle is fixed into holder 2. In this case, it is reasonable that the reference designators of the part be split between the two holders, 1 and 2. This will speed up the placement cycle time since the right head can pick up two parts and then go and place both of them. This is what our software will do. It attempts to split the placements among holders such that the load is balanced among all holders.

Of course, if that part is duplicated on the left side of the machine and an S nozzle is placed into holder 3, then three holders would be picking up parts and placing. This way both sides of the machine would be used.

Minimizing Nozzle Changes. Reducing nozzle changes is another important task. It was shown earlier that eliminating head contention also reduced the nozzle changes by two. Each nozzle change takes five to seven seconds. In a high-volume shop, it is important that the number of nozzle changes be minimized.

Since holders 1 and 4 have their own L and LL nozzles, it is important to assign all parts requiring the L nozzle to one holder and the parts requiring the LL nozzle to the other holder. The imbalance between such holders determines whether to assign parts requiring L and LL nozzles to one of these holders. For example, if there are parts requiring the L nozzle and their total placements are much more than the parts requiring the LL nozzle, then we assign the parts requiring the LL nozzle to one side and the parts requiring the L nozzle to both sides. In this case, we create one nozzle change on the side containing the parts with L and LL nozzles. The decision to assign the parts with the L nozzle to both sides of the machine or to a single side is made so as to minimize the total placements including the nozzle change cost.

Since the nozzle change time is not a constant time, we use a configuration parameter to set the cost of nozzle changes in terms of placements. The name of the configuration parameter is NOZZLE_CHANGE_COST. It has the default value of 2.5. This means that each nozzle change takes as long as 2.5 placements.

Prerotation and Rescan. Fuji part data has two fields called *prerotation* and *rescan*. If the prerotation field is set, the part must be prerotated before the camera can look at it. Therefore, the head that performs such placements can only pick up one part instead of two, thereby slowing down the machine. We keep track of such parts since they affect the load balance between the holders.

The effect of the rescan is the same as that of the prerotation. If the rescan field is set for a part, the head that picks up such parts can only pick up one part and not two. Again, we keep track of such parts and take them into account for load balancing among the holders.

Slot 34 and 54. Because of the construction of the Fuji IP2 machine, part placements from slots 34 (by holder 1) and 54 (by holder 4) have the fastest cycle time. Therefore, it is important that the high-count parts are assigned to these two slots. If the parts are assigned to holders 2 and 3, this does not hold. For holder 2, a part at slot 37 has the fastest cycle time, and for holder 3, it is slot 51.

Using slots 34 and 54 for high-count parts has the drawback of potentially wasting one to two slots, so if feeder space is at a premium this mechanism is not appropriate. However, if feeder space is not an issue, the cycle time can be reduced by using this mechanism. This is especially important for high-volume shops. We have provided a configuration parameter for users to choose whether to use this feature.

Slot Numbers. The center-to-center distance of the two holders of each head is 63 mm. The pitch of the feeder bank is 21 mm. The fastest pickup occurs when the parts for two placements made by the two holders of a head are 3 slots away from each other.

After the assignment of placements to holders is completed, we order the placements of each holder by slot number. In general, it may help the cycle time to pick up two parts with each head.

X and Y Coordinates of Placements. Another factor that can help reduce the cycle time is the distance between two placements on the panel. For example, if both holders of a head are picking up two parts, it will be faster if the two placements are close together on the panel. Therefore, after we sort the placements of each holder by slot (as explained above) then we order them by their separation on the panel.

Results and Discussion

One HP surface mount center was editing recipes to balance the load among the four holders. An engineer was doing this task. This was critical because of the high volume of some of the center's products. When our solution was available, the center tried it and got a very good result. Our solution was more than 16% faster than the recipe that was hand-optimized by an engineer. We should note that when this project was funded, the goal was to achieve 5% improvement, but in all cases we have exceeded this initial goal.

As explained earlier, one of the major issues was head contention. Formerly, the user had to edit the recipe to get around this problem. As a result, many users were not assigning certain parts to the IP2. This tended to increase the cycle time of their component placement machines because it increased the load on the fast machines. Since we have eliminated the head contention issue, users have moved more parts to their IP2 machines and have increased their throughput.

At other centers, the next device mechanism has saved 0.5 hours per shift on each line.

For contract manufacturing, especially for high-volume products, the cycle time reduction can provide an important competitive advantage. We can create recipes with our tools and give the optimized recipes to contractors to be used on Fuji machines.

Acknowledgments