# The Development of A Computer-Aided Process Planning Tool for Electronics Manufacturing Education

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## Abstract

In the 21st century, the rapidly evolving technological developments make educators constantly reassess the content of engineering curricula in the context of emerging fields. Therefore it is a must to create, apply, and evaluate innovative educational techniques and methods for the incorporation of these novel subjects into the engineering disciplines without compromising the cultivation of the traditional skills. In this case, Internet is rapidly being adopted in engineering education as a tool for enhancing the educational experience of students residing on campus as well as to expand the reach of unique programs beyond the local campus.

In the last few years, increasing product complexity, decreasing component size, and using double sided boards have made *Electronics Manufacturing* (EM) assembly lines more difficult and the economic troubleshooting of EM defects is one of the main problems facing all manufacturers. Dispensing, placement and reflow steps have been relatively improved with fully automated, accurate assembly machines and the use of robots. Although the authors have made significant improvements, it has been shown that the outcomes of the automated line have not produced a high enough level of the reliable yield percentage yet.

The objective of this current development is to make a contribution towards these EM processes by creating an interactive E-Manufacturing system of circuit board defects so that the defects that necessitate rework operation can be detected through EM assembly line. This system is also used as an educational tool in undergraduate and graduate level automated manufacturing courses to make the users more knowledgeable about the cutting-edge industrial trouble-shooting techniques.

## Background

To stay competitive in today's EM industry, there is a need to produce high quality products with the lowest costs and offer it to the market in the shortest time. These three key elements (quality, cost and delivery) are forcing the industry to look for new tools to improve the EM assembly process. When a surface mount line has down time because of process defects, it affects these three elements. *Statistical Process Control* (SPC) is a well-known tool used by many companies to monitor the assembly process. However, SPC does not reduce surface mount defects. It is just a tool, which identifies that something is wrong in the assembly process and alerts the operator to take corrective action and solve the problem. The complexity of the surface mount EM assembly process makes it very difficult to identify the true problem in the process.

A number of advisory systems[1], optimization studies[2], and simulation environment[3] have been developed and tested in the past decade, and their results and bench-markings have proved some improvements in EM Processes. But, none of these developments was used as an educational tool in any level of education.

Fidan has developed the first knowledge-based EM tool[4] and benchmarked his system with industrial runs. This was an intuitive visual system developed via *Visual Basic* (VB) for the surface mount attachment processes. He also used these developments in his graduate level *Computer Integrated Manufacturing* (330:151g) and undergraduate level *Industrial Automation* (IT407) courses to explain the Computer Aided Manufacturing Process Planning concept and run some case studies with his developed system.

## Electronics Manufacturing Process

The surface mount EM process involves multiple machines with many variables, which are often difficult to control. This makes it hard for the operator to identify the problem and take the correct action when defects occur. This project targets the development of an intelligent e-manufacturing system which emulates human thinking, expert knowledge and provides assistance to the surface mount operator in the decision making process during problem solving. Surface mount processes contain dispensing, placement, and attachment steps. Right after the inspection and quality control, defective components and sections are reworked. Figure 1 presents the relationship between the surface mount EM processes and rework. The surface mount rework refers to the general technical problem of removing and replacing defective circuit components on a printed circuit board. A variety of different rework methods have been successfully developed and tested during the last decades of the 20th century[5], but it has also been proven that none of them has perfectly produced final reliable joint throughputs out of the manufacturing line. Now the new objective is to develop alternative methods instead of utilizing manual, semi-automated or automated rework systems. The technology, which has been under investigation now focuses on eliminating the causes of these manufacturing problems since the old technologies practiced are costly, complicated, and require skilled operators. The rework operation involves several steps: removing defective components, cleaning the vacant component sites, dispensing new solder paste, placing new components, and then reflowing the joints. As it can be seen in Figure 1, the function of the rework process is to remove and replace individual components from a fully-populated board without damaging the board itself, the surrounding components, or the solder joints of the surrounding components. To date major advances have been made in this direction for EM processes and rework steps by the authors[6-8].

The purpose of this project is to make a contribution towards this surface mount EM and rework by creating an interactive e-manufacturing system of circuit board defects so that defects requiring rework operation can be detected through the EM line. With the development of this system, the rework will be removed from the EM line and assembly line process parameters, which cause some reliability problems (such as solder balls, insufficient solder at joints, burnt joint connections, bridged leads, voids, skewed leads, and unformed joints) will be troubleshot directly. The developed system will also be accessed via Internet and used in undergraduate and graduate level automation, and manufacturing processes courses to aid the lectures and labs.

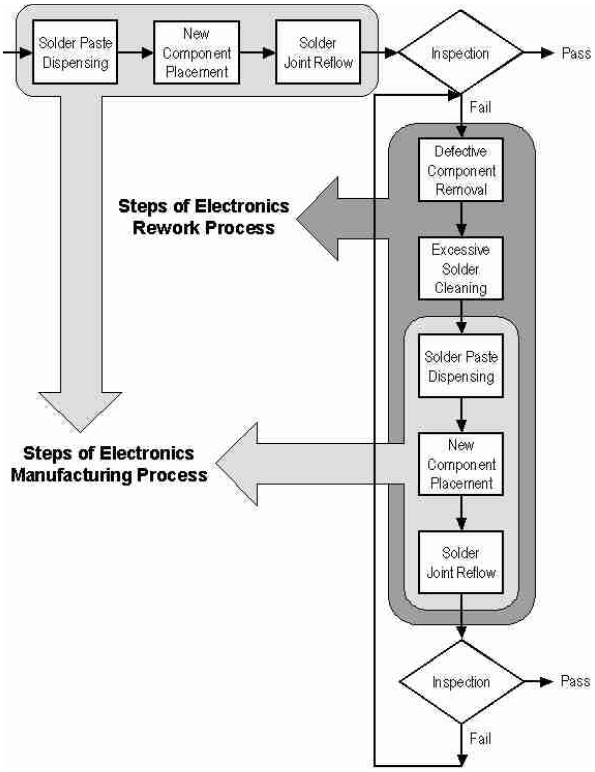


Figure 1: The Relationship between the Steps of Rework and Electronics Manufacturing

As it can be seen in Figure 1, solder paste dispensing, component placement, and joint level reflow are the common processes in both EM and rework operations.

### a. Solder Paste Dispensing

The most common method for solder paste deposition is stencil printing. In this process, solder paste is deposited onto the attachment pads of the board through corresponding holes made in a metal foil. For fine-pitch components, the printing process becomes critical because there is insufficient room to elongate the solder stencil aperture. For very fine-pitch components, it is not uncommon to achieve a print efficiency of less than 60 percent. Aperture size and stencil thickness need to be adjusted properly to ensure the highest transfer ratio (paste deposited vs. aperture volume). In general, the apertures should be oversized slightly compared to the attachment pad geometry to increase the solder deposit volume and transfer ratio. However this may lead to an increase in solder ball formation.

### b. New Component Placement

The strategies used to place components on boards can be divided into in-line, mass, sequential, and simultaneous placement. In high volume manufacturing, dedicated sequential or mass placement may be performed. In most cases, flexibility is important to accommodate new products and components. Typically EM assembly uses sequential component placement. Two types of placement equipment are used for sequential pick-and-place operations; the first is an X-Y gantry style, and the second is fixed fixed-head moving-table placement machines. The overhead equipment offers high flexibility, medium placement speed, high accuracy, and minimal accelerations or movement of the board. In contrast, the table movement machines (usually rotary turret heads) offer high placement speeds and medium accuracy and flexibility, and impose high accelerations on the board.

Another important feature of the placement system that affects the EM process is the vision system. A major issue is the ability of the equipment to recognize features on the board and component and accurately place the device by aligning the device leads to the attachment pads on the board. Illumination of the package from a lower angle, namely side-lighting, may be required to prevent erroneous placements.

### c. Joint Level Attachment

Joint level formation between the component and printed wiring board is accomplished with the reflow process in order to maintain the permanent link. The heat transfer mechanisms used in the mass reflow solder process include convection, radiation (using radiation sources) and condensation (vapor phase). The most popular method of reflowing solder is based on forced convection or IR radiation. Some other methods of solder are vapor phase, laser, and hot bar. In addition to mass reflow soldering, boards often are subjected to wave soldering operation. In wave-solder applications, the board is passed over a wave of solder where the solder is attracted to all wettable surfaces, including component leads. Wave temperature must be controlled carefully to prevent the solder joints from burning. Uniformity of temperature across the board and within a component is a primary goal of any reflow system.

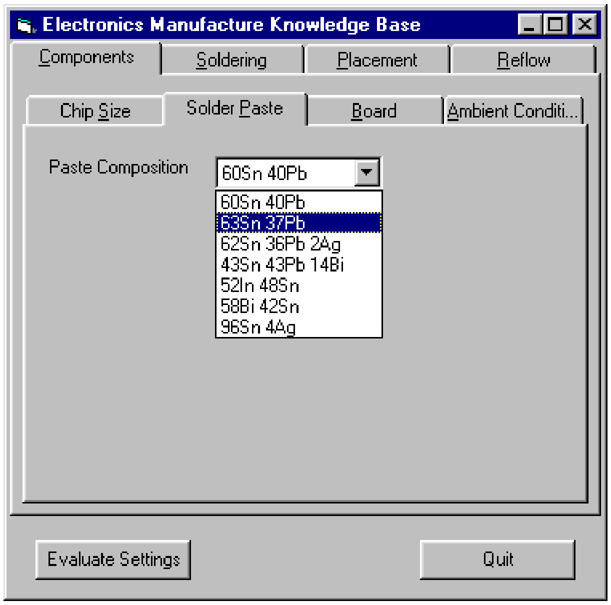
## Current Development

Laser soldering is a common reflow process practiced in EM and rework. None of the other attachment processes has potentially been practiced in rework since laser's localized application feature makes it the best for attachment. As can be seen in Figure 2, the authors have developed an e-manufacturing computer software tool for the laser reflow. This developed system uses VB 5.0. This system will also be included into the final EM system eventually.

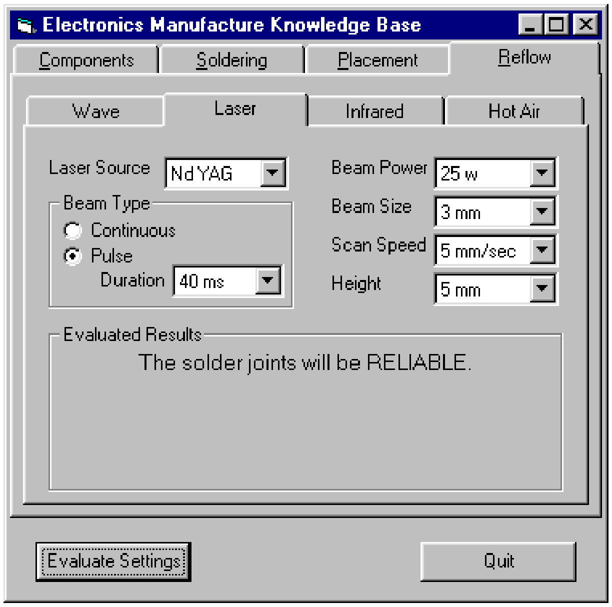
The data and knowledge available in the system were collected from various numbers of catalogs, handbooks, technical papers, and textbooks. The information gathered was tabulated into Excel data folders based on laser and solder type, and then they were all coded into the system.

The developed system for the laser reflow runs as follows: After clicking on the "Reflow" tab four buttons are displayed on the window. Each of those buttons is labeled with a different process that could be used in that step. Next the user selects one of the buttons, we will use [Laser]. This results in the parameters for laser reflowing. Some of the parameters are Laser Source, Beam Power, and Scan Speed etc. This particular process provides all of the values in drop-down lists for the user. Once all the required information is selected the user can click on [Evaluate Settings] to evaluate the settings and return the outcome of actually implementing this set of parameter values in the electronics manufacturing process.

The knowledge collected and the outcomes of the system developed have been double-checked and benchmarked with the experimental tests performed at the Iowa Laser Inc. and UNI Material Testing Lab. The joints that have solder balls, unformed joints, bridging, voids, and bent were classified as 'unreliable'. The ones that have no such things were called 'reliable'.



Paste Composition: 60Sn 40Pb



Laser Source: Nd YAG

Beam Type: ● Pulse

Duration: 40 ms

Beam Power: 25 w

Beam Size: 3 mm

Scan Speed: 5 mm/sec

Height: 5 mm

Evaluated Results: The solder joints will be RELIABLE.

Figure 2: The currently developed E-Manufacturing System and a Sample Case Study

## Industrial profits

Although automated surface mounted EM and rework stations have been developed in the past, none of them was able to remove the rework process out of the EM line. Now one possible solution is detecting the problems causing the joint level defects and trying to find some process level solutions to obtain high quality, defect-free outcomes. In order to accomplish this objective the best option is to create an expert e-manufacturing tool. Such a tool contains all the knowledge needed in surface mount assembly manufacturing and reduce the defect level to zero eventually. The first development has been done for the laser attachment since the authors had the industrial partners in this field. The following list summarizes the benefits for this newly developed system for laser soldering.

- This system provides a cost-effective means for assembly line enhancement.
- The number of the defects causing scrapped circuit boards is reduced or totally eliminated.
- Quality and productivity increase while reducing the defect rates.
- Cause-and-effect relationships in the knowledge base of e-manufacturing tool decrease the time spent in new design efforts.
- System could be used for updating the EM line processes required by new technological advances in electronic designs.
- Modular nature of the system increases the system utilization, allowing the manufacturers to solve specific problems in the EM line.
- Easy-to-use, easy-to-learn and easy-to-update structure of the developed tool supports the instructor and student in computer integrated manufacturing education.

## Educational Practices

Hands-on experience and labs are an important part of any engineering course. They make the subject matters more comprehensible and realistic. There are many process planning software packages available on the market to support this objective in any lab or classroom environment. Authors have used the current EM process-planning tool in the following courses.

*Computer Integrated Manufacturing* (330:151g)[9] is a graduate level course. The developed tool was practiced in 330:151g's process planning section and benchmarking studies were performed with the support of Iowa Laser Technology, Inc. Students enjoyed practicing process planning tool, laser soldering the boards, and benchmarking the reliability tests.

*Industrial Automation* (IT407)[10] is a senior level course. To explain the computer-aided process-planning concept, the developed tool was presented to students and some case studies were accomplished using the computer lab. Sample finished boards were presented to students after they had run the computer-aided process-planning tool. Students learnt the construction of the tool developed, algorithms written, and finally the importance of a computer-aided process planning system in industry was explained with the help of the system.

Using such a tool enhanced the 330:151g and IT407 courses and labs. The assessment received from the course students proved that students enjoyed running the tool and seeing the real results of numeric runs on a finished circuit board.

## Conclusion

This intuitive system will definitely eliminate the major problems causing the surface mount rework operation. The other common reflow methods, solder paste dispensing, and new component placement will be added into the current system in the future. The current system has been used in the undergraduate and graduate level manufacturing courses. It has been observed that students have enjoyed running the system, and practicing their learnings in computer-aided process planning, manufacturing processes, and process control fields. Additional process level knowledge and constraints will be added in the near future.

## Acknowledgments

This project is currently being funded by NSF INTERNATIONAL (NSF Award # 0215760) and TUBITAK MISAG Divisions. The initial development of the laser soldering project was funded by NASA/ISGC. The authors greatly appreciate the technical assistance of Iowa Laser Technology, Inc., Cedar Falls, IA, Center for Integrated Electronics, RPI, Troy, NY, and Advanced Innovative Technologies, Inc., Troy, NY. Special thanks are also extended to Alan Lamborn, Dr. Marc Timmerman, and Dr. Recayi Pecen.

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## Biographical Information

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Dr. Ismail Fidan is a faculty member at the MIT department of Tennessee Tech University, Cookeville, TN. He began his academic appointment in August 2000. Dr. Fidan received his PhD in Mechanical Engineering from Rensselaer Polytechnic Institute in 1996. He is a senior member of IEEE and SME, and member of ASEE, NAIT, ASME, TAS and SMTA. Dr. Fidan also serves as an associate editor for the IEEE Transactions on Electronics Packaging Manufacturing and editorial board member for the NAIT Journal of Industrial Technology and SAE Journal of Manufacturing and Materials. Dr. Fidan is the recipient of 2003 Tennessee Tech University Exemplary Course Project Award, 2003 SME Outstanding Young Manufacturing Engineer Award, 2002 Provost 'Utilization of Technology in Instruction' Award, 2002 Technology Award by The Institute for Technological Scholarship, 2001 NAIT Outstanding Professor Award. His teaching and research interests are computer integrated design and manufacturing, electronics manufacturing, and manufacturing processes.

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