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SYSTEMATIC MANUFACTURING PROCESS PLANNING OF SURFACE MOUNTING ASSEMBLY

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Abstract

The present article shows a systematic approach to surface mounted assembly (SMA) manufacturing process planning in the electronic industry. It discusses the primary goal hierarchies (or 'state maps') of the four basic types of SMA-s showing the theoretical stages of their production. Then it derives their practically possible main manufacturing processes with a step-by-step technological analysis of the theoretical routes in the 'state maps'. Finally it discusses the practical advantages of the application of this kind of systematic process planning in general.

Keywords: manufacturing process, surface mounting assembly (SMA).

1. Introduction

The aim of this article is to show an example of the successful practical application of some industrial engineering concepts and techniques in the field of electronic engineering, and to draw some general conclusions from this example.

It proved to be difficult to find all the possible manufacturing processes of surface mounted assemblies (SMA-s) in a non-systematic way, that is why the author developed a systematic process planning procedure, based on a special diagramming technique, for this specific engineering purpose. It has been applied successfully at the Hybrid IC Division of Remix Co. in Budapest.

The present discussion focuses on the basic assembly technologies, and disregards direct assembly of semiconductor chips onto the PC board (bare chip and wire, flip chip, tape automated bonding, etc.), or assembly with conducting glue. If one wants to apply any of these special assembly techniques then it will be easy to modify these models in accordance to the chosen special technology. The important point is to understand how this kind of diagramming and process planning procedure works and why it is useful. If it is clear, any kind of modification and further development will be easy, so it is needless to draw several big graphs covering every potential manufacturing technology.

2. Systematic Manufacturing Process Planning

The manufacturing of a new product or product line should be planned in three main stages (KOCSIS, 1985).

Stage 1: goal hierarchies of the product.

Stage 2: manufacturing process networks (based on the goal hierarchies).

Stage 3: manufacturing system plan (based on the process networks).

There are two types of goal hierarchies: primary and secondary. Primary goal hierarchy is a graph showing the connections of the different semi-finished products between the finished product and the components and row materials at the starting point. If it is justifiable to break away from tradition, the author prefers to call the primary goal hierarchy graph the 'state map' of the product. The processes which can be derived from this state map are the possible main processes of manufacturing. We call 'main process' the one which increases the degree of natural completeness of the product, and 'support process' which does not. For instance, solder paste screen printing is part of the main process, but the photolitographic masking of the screen is not. The latter is necessary for the production, but does not increase directly the degree of natural completeness of the product itself.

The resource needs of the main process – like solder paste, printing screen, etc. in the example above – form the bases of the secondary goal hierarchies. Support processes are derived from these secondary goal hierarchies (e.g. the 'state map' of the printing screen preparation, etc.), and they assure that the main process takes place properly. After clarifying the whole network of main and support processes we are able to plan the whole manufacturing system, including both the production line and the support facilities (KOCSIS, 1985).

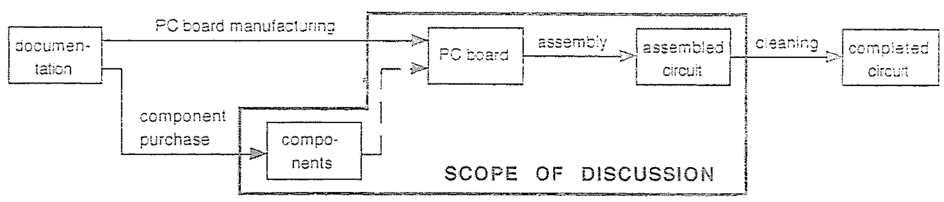

Fig. 1. Sketchy graph of SMA manufacturing process, showing the scope of the present discussion

3. The Scope of the Discussion

The complete production planning with all the three stages would need a whole book not just an article. There are almost countless variations of manufacturing systems depending on the specific needs of the manufacturer and on the special circumstances (physical and monetary conditions, etc.) in the factory, so the manufacturing system must be 'tailor-made' for the factory concerned.

This paper discusses:

'stages 1 and 2 of SMA production planning.

'the planning of the main manufacturing process.

The planning of the manufacturing system (stage 3) and the support functions (secondary goal hierarchies and support processes) are beyond the scope of this paper. The roughly outlined manufacturing process graph of surface mounted assemblies is shown in *Fig. 1*.

The graph in *Fig. 1* is a standard 'activity-on-arrow' network diagram, originating from project management. (SHTUB, BARD, GLOBERSON, 1994). Arrows mean activities, i.e. specific tasks that are required by the process or project, use up resources, and take time to complete. Nods mean events, i.e. identifiable states occurring when every predecessor activity has been finished. therefore the successor activities can be started. Events themselves have no time duration and use no resources. They are merely points on the network, necessary for defining the activity precedence relationships. Dashed arrows mean dummy activities, which indicate particular precedence relationships without any tasks to be completed between their starting and ending nodes. Therefore dummy activities have no time duration and use no resources, just represent precedence relationships. The manufacturing process plans in this paper are this kind of network diagram.

The problematic activity, which can be done in several different ways, is assembly. The present article focuses on the possible sequences of this problematic phase of the manufacturing process, and does not cover component purchasing, PC board manufacturing, and cleaning. That is why all the manufacturing process graphs begin with the second halves of the arrows representing component purchasing and PC board manufacturing, and end in the first half of the arrow representing cleaning.

4. The State Maps of SMA-s

Our goal is the mass-production of SMA-s. This goal can be divided into four sub-goals. the mass-production of the four basic types of SMA-s (BLANKENHORN, 1990; BOSWELL, 1990):

- pure SM, single sided (P1),
- pure SM, double sided (P2),

- mixed, with SMD-s on one side (M1),
- mixed, with SMD-s on both sides (M2).

So we have to draw four state maps (primary goal hierarchy graphs).

At the beginning we divide assembly into two activities: component mounting and soldering. In accordance to this degree of resolution of our model the symbols shown in *Fig. 2* will be used on the state maps.

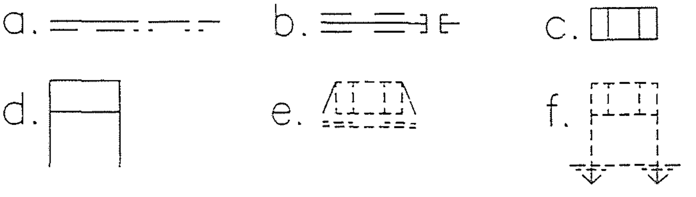

Fig. 2. Symbols used on the state maps. a) single sided PC board b) double sided PC board with via c) surface mounting device (SMD) d) through-hole mounted component (THC) e) SMD solder joint f) THC solder joint

Figs. 3–6 show the state maps of the four basic types of SMA-s. The assembled circuits can be seen at the top, while the bare board and the components at the bottom. The states in the same level of the graph can be reached with the same number of elementary transformations from the starting point at the bottom, and the completed product at the top can be reached with the same number of elementary transformations from any of them. Elementary transformation means either the placement or the soldering of components of the same type (SMD or THC) on the same side of the PC board.

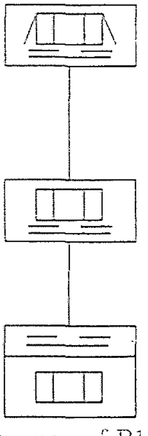

Fig. 3. State map of P1 assemblies

The lines on the state maps of P1 and P2 circuits connect such states which are one elementary transformation far from each other. (See *Figs. 3* and *4*.) At first we examine the possibility of such technological solutions which would cause two or more elementary transformations at the same time, i.e. two or more level jumps upwards on the state maps. We can not mount two sides in one step. It is also impossible to mount and solder simultaneously. We can solder both sides of P2 circuits in one step with reflow soldering, if we glue the components onto the board. Otherwise they would drop down from the bottom side of the board if we solder them in a horizontal position, or from both sides if we solder them in a vertical position. Screen printing of the solder paste onto the second side of the PC board is impossible, because the whole printing area must be supported and the printing on the bottom side would be smeared. It can be transferred only by syringe or by pin transfer one-by-one onto every single soldering pad, which are far less productive technologies than screen printing. If we produce small batches we can do this and we can draw a line between the right-side state of the middle level and the top state in the state map of P2 assemblies. But in the present discussion we deal with mass production only, so we can neglect this possibility.

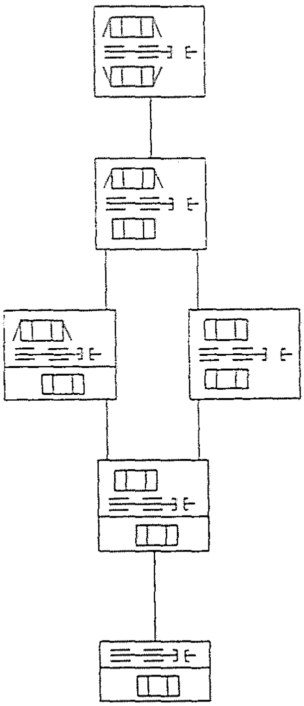

Fig. 4. State map of P2 assemblies

Finally we have to examine the existence of technologically impossible or unwanted transformations on the state maps. We can not find such in the P1 and P2 graphs. The conclusion is that there is one possible manufacturing main process for P1 circuits and two for P2 ones at the present degree of resolution of our model.

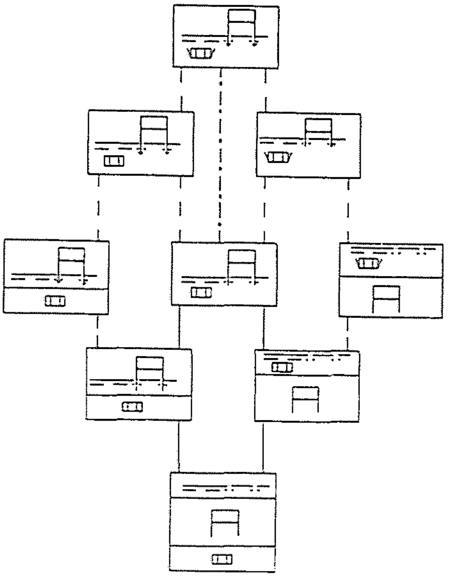

Fig. 5. State map of M1 assemblies

On the M1 state map, however, we can find a possibility of two elementary transformations in one step. This possibility is the wave soldering of SM and TH components together, which would be much more difficult separately. A dotted broken line represents this possibility in *Fig. 5.* and the broken lines of the parallel single elementary transformations show that they have become unnecessary. Such a 'level-jumping' makes needless not only the parallel lines, but some of the ones at the lower levels, as well. If all of the lines leading from a state upwards (towards the completed product) are unnecessary, then the state itself and all the lines leading there from below are also unnecessary. We must check every state and line level-by-level down to the bottom, and mark the needless elementary transformations with broken lines. Since all the transformations represented by the remaining unbroken lines are technologically possible, we can see that M1 circuits can be assembled in two different ways.

In the case of M2 circuits we can also jump from level three to the top with wave soldering, marked by a dotted broken line in *Fig. 6.* Stepping downwards level-by-level we can find all the needless transformations. Among the remaining ones we can find three transformations which are technologically unwanted, represented by dotted lines. In each case we should solder SMD-s with inserted THC-s on the same side. Both wave soldering

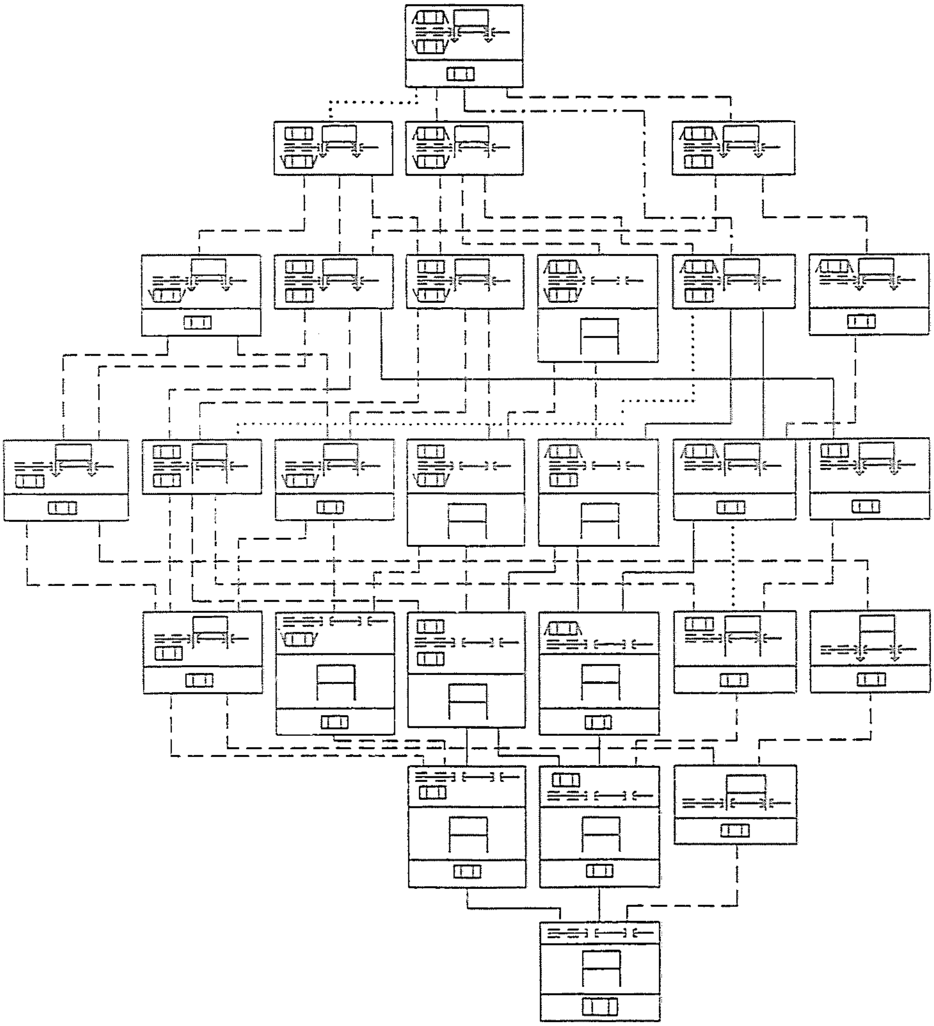

Fig. 6. State map of M2 assemblies

and reflow soldering would be problematic in this way (thermal shock of conventional TH components, shadowing of SM solder pads by large THC, etc). These unwanted or impossible lines of the graph make needless some other lines on the lower levels in the same way as the ones made unnecessary by level-jumps. If we track these needless lines downwards then the remaining lines show the possible manufacturing processes. *Fig. 6* shows that M2 circuits can be assembled in four different ways.

Summarizing the usage of the state maps: we must find every possible level-jumping technological step and every unwanted or impossible ones,

and track the needless ones downwards in both cases. The remaining paths of the graph show the possible main manufacturing processes. Two new abbreviations are used on the list of the manufacturing processes below: SM1 means SM devices on the through-hole components' side, SM2 means SM devices on the through-hole solder joint side of the PC board. The possible main processes derived from the state maps are the following ones.
P1: mounting – soldering.
P2/1: mounting – soldering – mounting – soldering.
P2/2: mounting – mounting – soldering – soldering.
M1/1: SM mounting – TH mounting – SM and TH soldering.
M1/2: TH mounting – SM mounting – SM and TH soldering.
M2/1: SM2 mounting – SM1 mounting – SM1 soldering - TH mounting – SM2 and TH soldering.
M2/2: SM1 mounting – SM2 mounting – SM1 soldering – TH mounting – SM2 and TH soldering.
M2/3: SM1 mounting – SM1 soldering – SM2 mounting – TH mounting – SM2 and TH soldering.
M2/4: SM1 mounting – SM1 soldering – TH mounting – SM2 mounting – SM2 and TH soldering.

5. The Possible Main Processes of Assembly

After drawing and analysing the state maps we can examine the possible main processes in detail. Increasing the resolution of our model we can say that SMD mounting and soldering can be carried out in two different ways (CAPILLO, 1990; PATAKI, 1986):
1. mounting = solder paste screen printing + component placement, soldering = reflow soldering; 2. mounting = glue application + component placement + glue exposure, soldering = wave soldering.

There is no need to go into more details about through-hole component assembly at this degree of resolution of our model yet. THC soldering is always wave soldering.

The symbols used in the manufacturing process graphs below are shown in *Fig. 7*. Some of them are new, others were used on the state maps, but with more general meaning, in accordance with the rougher resolution of the model. The other symbols, which are not shown in *Fig. 7*, mean exactly the same as before.

Abbreviations identifying the activities of the manufacturing processes are the following:

sp – solder paste screen printing,
cb – component placement onto the board,
rs – reflow soldering,
ga – glue application,

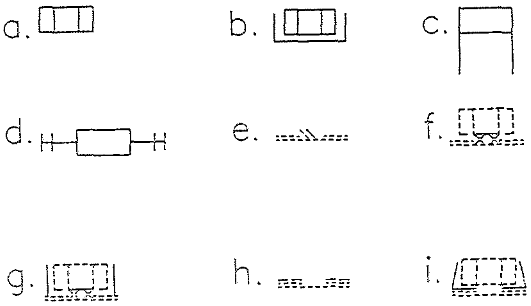

Fig. 7. Symbols used in the manufacturing process graphs. a) SMD ready for mounting b) SMD packaged by the supplier c) THC ready for mounting d) THC packaged by the supplier e) glue drop f) exposed glue g) SM solder joint made by wave soldering h) solder paste i) SM solder joint made by reflow soldering

ge – glue exposure,
cp – component preparation for mounting,
cm – TH component mounting,
ws – wave soldering.

At this finer degree of resolution process P1 has two different versions. P1.1 with reflow soldering, and P1.2 with wave soldering. Process P2/1 has two versions as well, P2/1.1 with reflow soldering on one side and wave soldering on the other, and P2/1.2 with wave soldering on both sides. P2/2 has only one version, with wave soldering on both sides. M1/1 and M1/2 both have only one version, with wave soldering. M2/1 and M2/2 both have only one version, with wave soldering on both sides. M2/3 has two different versions, M2/3.1 with wave soldering on both sides; and M2/3.2 with reflow soldering on the THC side of the board, and with wave soldering on the other side. M2/4 has two versions as well, M2/4.1 with reflow soldering on the THC side of the board, and with wave soldering on the other side; and M2/4.2 with wave soldering on both sides.

The network diagrams of manufacturing processes P2/1.1 and M2/4.1 are shown as examples in *Fig. 8* and *Fig. 9* respectively, using the same kind of network diagramming technique as in *Fig. 1.* The network diagrams of the other manufacturing processes are not shown here because of the limited length of this paper, but the author is happy to send the reader a copy of the other process network diagrams as well, if required.

The resolution of our model should be further increased only after making some basic decisions about the manufacturing technologies and the manufacturing system. The choice of the manufacturing technologies (e.g. infrared or vapour phase reflow soldering), materials (e.g. glue exposable by UV+heat or just by heat), and equipment (e.g. serial or parallel mount-

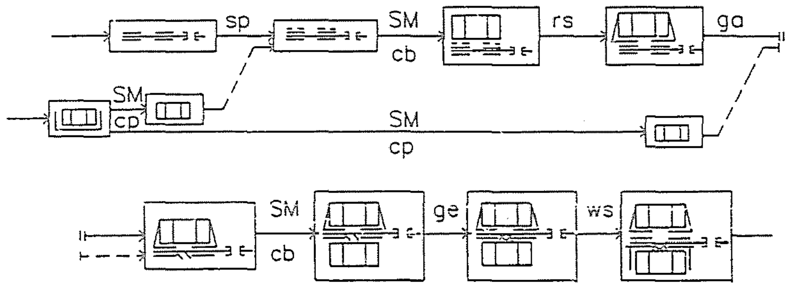

Fig. 8. Network diagram of manufacturing process P2/1.1

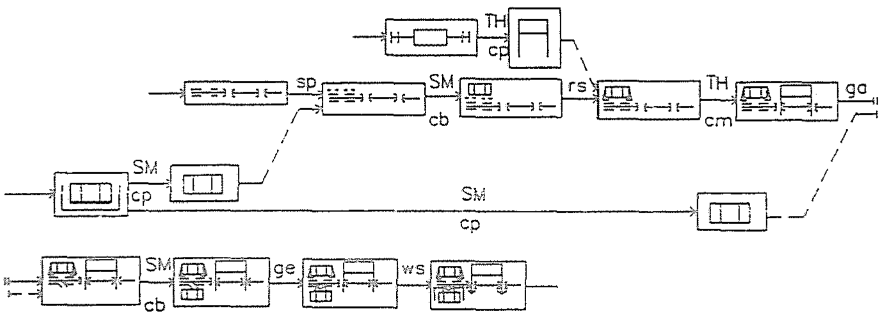

Fig. 9. Network diagram of manufacturing process M2/4.1

ing machines) decreases dramatically the number of possible procedures to be considered and built into the model. If we tried to take every theoretically possible variation into consideration we would make a vast amount of unnecessary process plans.

We can go into details in those areas which need more thorough examination. In such cases we should increase the resolution of our model, introduce new symbols, and draw the state maps and the network diagrams only for these particular areas, not bothering with the problem-free parts of the graphs. It means a kind of selective zooming and the usage of more detailed sub-maps and sub-networks in some limited areas.

Which manufacturing process is the best? It depends on the particular circuit design, on the particular production system, and even on the current workload of the different pieces of equipment, etc. Choosing the optimal process is a typical multiple criteria decision making, depending on the circumstances. There is no best manufacturing process in general.

One must not forget to draw and analyse the secondary goal hierarchies and the network diagrams of the support processes, as well (KOCSIS, 1985). Support processes are neglected too often during the planning phase which causes serious problems after setting up the production system. Support processes include, for instance:

– material handling (including the storage and forwarding of PC boards, components, raw materials, chemicals, work in progress, finished SMA-s, etc. within the production system),

– inspection (including bare board test, component test, other material quality tests, mounting checking, finished SMA in circuit and functional test, etc.),

– maintenance and servicing of the manufacturing and support equipment, and many other essential tasks. After planning both the main and support processes we can start designing the manufacturing system.

6. Benefits of the Application of This Technique

KMETOVICZ (1992) assembled a list of the problems that significantly impact product development. This list was assembled from firsthand experience in leading new product development efforts and by collecting feedback from an assortment of project managers. On this list – among others – we can find:

- shortage of design tools,
- internal miscommunication,
- difficulty in communicating concepts.

The state maps and the network diagrams discussed above can be very useful design tools, and can help to form a common language between technological development and production, making communication and joint problem solving more effective and efficient. CARTER and BAKER (1992) also emphasise the importance of technologies for communicating and collaborating between product designers, manufacturing process planners, and other professionals during the concurrent (simultaneous) engineering of new product designs and manufacturing processes. They call 'interface documents' those materials which can help the cross-functional communication of the professionals mentioned above, and can form a useful part of their library of information. The diagrams presented in this paper proved to be very useful for this purpose at Remix Co.

The network diagrams of the manufacturing processes can be used for production management purposes as well (WATERS, 1991). Determining or estimating the activity times we can calculate the completion time of the whole manufacturing process and find the so-called 'critical path', i.e. the most time consuming sequence of activities between the start and the end of the network, which determines the completion time. We can easily simulate the production management consequences of technological changes by such a quantitative network analysis.

7. Concluding Remarks

The systematic approach described above helps to create a clear picture of all the possible stages and processes of surface mounting assembly and not to leave any of them out. The advantage of this procedure is not only having some useful charts in the end but the planning process itself. This systematic planning process with its visual aids forces the planners to come along step by step, thinking everything over in a logical way. It helps to discuss problematic issues, to generate ideas, to choose the best solution, and to communicate in an effective and efficient way about the manufacturing process. This approach can obviously be applied in several other fields of engineering, not only in surface mounting technology, and not only in the electronic industry.

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