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Inspection and test equipment is expensive, produces nothing and does not contribute to the company's bottom line! Such may be the thinking of many. But as today's electronic assemblies use more and ever smaller components that are impossible to inspect manually, and components that are impossible to test electrically, the main question is "What costs are manufacturers absorbing because they do not have an Automated Optical Inspection system?"

It is in regions with high labour costs that the value of reduced Manual Visual Inspection (MVI) is probably most easily understood and measurable by manufacturers of electronic assemblies.

As the use of AOI systems becomes more common in the industry, questions regarding the return on investment (ROI) associated with their implementation are also raised more frequently. Some of the major aspects related to the return on investment of AOI are the reduction of manual visual inspection, the cost of rework and retesting, and the cost of In-Circuit Testing (ICT).

A Practical Case Study

Considering a practical case of a UK company that has implemented AOI in post-reflow, a 3 shift operation with 5 inspectors/shift (total of 15 inspectors) dedicated to MVI has now safely been reduced to 3 inspectors/shift (total of 9 inspectors), resulting in a reduction of headcount by 6. The reduction would come essentially from the elimination of manual top and bottom side inspection.

Effective Headcount Reduction: 6 people

Annual Wage Cost (incl. benefits): 25,084 Euro/person

Savings: 150,504 Euro

The numbers used in this case are based on a UK example; one can imagine higher savings in environments with higher social costs and wages. Furthermore, headcount reductions should be understood as an opportunity to redeploy resources towards other, possibly more value-adding tasks which would in turn need to be calculated as part of the ROI on AOI.

Further Cost Savings

Further savings derived from the implementation of AOI could be obtained by moving from HASS (Highly Accelerated Stress Screening – 100% testing) to HASA (Highly Accelerated Stress Audit – sample testing). The savings would come both from head count reduction and reduced consumption of nitrogen:
Reduced nitrogen consumption savings: 11,200 Euro

Headcount reduction 3 shifts to 1: 2 people

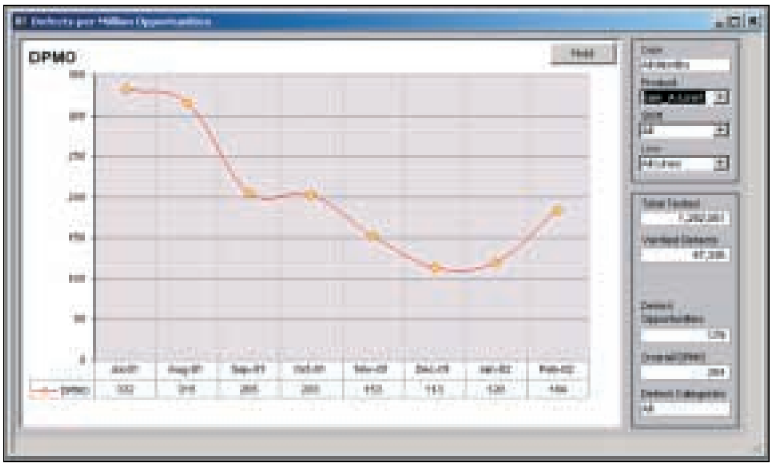
Headcount reduction Savings: 50,168 Euro

Finally, for this specific case, it was estimated by the manufacturer that there would be a labour cost saving based on improved yields in the vicinity of 22,000 Euro.
If all of those savings are added up, we obtain a total projected saving of 233,872 Euro over a period of one year.

Based on the scenario above, the pay back time for a mid-range to high end AOI at today's prices comes to less than twelve months. If a full solution concept with offline
programming station, in-line repair station, process control, process capability and yield management software is used, pay back will ultimately be even increased.

With the implementation of such tools, customers can identify specific problem areas and work on them to reduce the DPMO (defects per million opportunities) rate. The graph of Figure 1 illustrates this for a seven month product run

Figure 1 - DPMO Rate for a Seven Month Production Run



PRODUCT	Failures	Cost of Rework/ PCB	Total Cost of Rework	Cost of Electr. Test/PCB	Total Cost of Re-Test	TOTAL COST
Paris	1720	0,16	275,20	2,66	4.569,70	4.844,90
Helen	9955	0,15	1.493,25	3,35	33.383,10	34.876,35
Achilles	4671	0,62	2.896,02	3,06	14.301,67	17.197,69
Ajax	363	0,16	58,08	3,26	1.182,00	1.240,08
Hector	10369	0,32	3.318,08	2,84	29.396,12	32.714,20
Cassandra	3695	0,16	591,20	3,32	12.254,84	12.846,04
Athene	10083	0,40	4.033,20	3,71	37.405,91	41.439,11
Priam	51	0,45	22,95	1,80	91,71	114,66
Menelaus	3287	0,91	2.991,17	5,05	16.613,81	19.604,98
Total	**44194**		**15.679,15**		**149.198,85**	**164.878,00**

Table 1 - Costs of Rework and Re-Test (all figures in Euro)

where a total of 1.29 million boards were inspected; in July 2001, the manufacturer had 4690 real defects but had seen a reduction to 2999 defects by January 2002 (decrease of real defects of 36%), which translates into a drop of the DPMO rate by more than 120 points total.

The point is that the so-called 'peripherals' deserve more attention by customers. The actual way in which AOI is implemented and supported through 'peripherals' is key to a fast pay-back. The additional outlay is quickly justified when manufacturers realise that a strategy that aims at improving the manufacturing process pays 'for itself'.
However, the scenario as it has been sketched out above is incomplete, as it does not explicitly account for:

- The cost of escapes at MVI (defect coverage really is somewhere around 60-70% at best);
- The cost of defects created through manual handling of the boards at MVI;
- The cost of unnecessary re-test at ICT and FT caused by misclassification at MVI (false calls).

The latter is difficult to assess, but it is possible to define the total cost of re-test as the cost factors related to the diagnosis, rework and subsequent re-test of an assembly.

The cost of rework and re-test

It makes sense to use a cost example which is spread over several different builds to account for the differences in complexity, density, process yield etc.
Case:

9 different builds

280,000 assemblies

Min # components/assembly: 33

Max # components/assembly: 804

Avg. yield: 83.3%

Table 1 reflects the cost for rework and re-test if errors on the topside alone of 9 SMD assemblies are allowed to flow through unhindered to ATE testing. The cost of diagnosis, rework and re-test for a failed PCBA can obviously be drastically reduced through the use of an AOI system in the production line. Typically, downstream yields raise significantly once AOI has been implemented, i.e. anywhere into the range from 95% to 99+%.

Table 2 - Reduction in diagnostic time (minutes)

Reduced Diagnostic Time Saving		
Avg. time of FT Diagnostics	3	min
Avg. time of AOI Diagnostics	0,3	min
Total board assemblies/year	280000	
Avg. Yield across all assemblies	0,833	%
Labor Rate/Repair Technician (fully burdened rate)	60	
Diagnostic Time Saved by AOI	126252	min
Cost of Time Saved:	126.252	

It is somewhat difficult to say exactly how much of the unnecessary re-test can be avoided, how much the cost of false classification by MVI might be, and how much the use of electrical testing could actually be reduced. However, it is possible to use the reduction in diagnostic time at functional test brought about by the use of AOI as an indicator for the savings one can hope to achieve at a very minimum (Table 2).

AOI vs No-AOI

Based on this specific case, the payback time of an investment in a fully production-line capable, high-end AOI system would also be in the vicinity of twelve months – once we have figured in the savings from reducing personnel used in MVI.
Furthermore, one must consider the not easily quantifiable cost of unnecessary retest, the cost of defects, which have been added to the PCBA in the course of the handling process after defective PCBA's have been taken off the line and sent to diagnosis and electrical test. Typical problems found in repair are:

- Faulty repair;
- Bad soldering;
- THT not soldered;

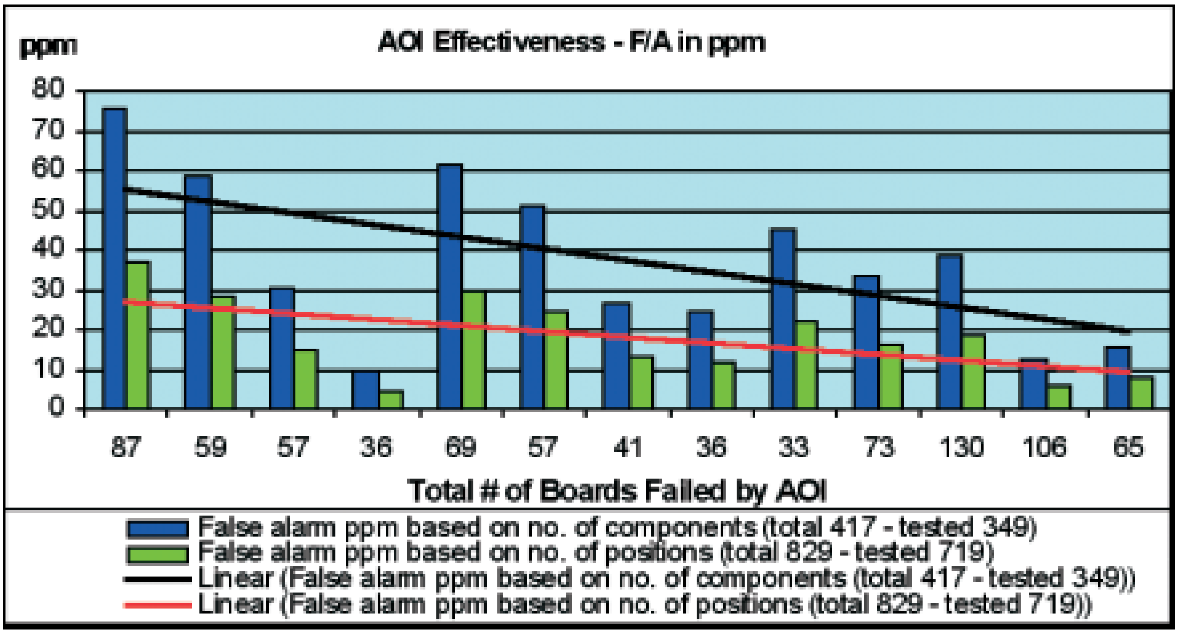


Figure 2 - Automated Optical Inspection Effectiveness

- Components broken off;
- False classification at repair.

One of the true black spots is the lack of control over the actual re-soldering process in repair. According to an NPL study in the UK, about 2/3 of all operations do not control the temperatures of the tip of soldering irons or the number of permissible touch-ups.

This is only seemingly unrelated to the issue of return on investment of AOI. After all, the percentage of defects which are caused by false classification and manually handling boards in MVI and at test are an add-on to the actual production defects – and hence an additional, and completely unnecessary cost.

It seems obvious that the reduced reliance on ATE will also minimise the related costs in this area. AOI clearly is a means to reduce the burden placed on rework and retest, hence a way to use that resource more effectively as such.

Completing the picture

At this point, we have looked at the cost of reducing manual inspection and the cost of rework and re-test. Again, this is only a part of the picture. There are additional considerations:

- What is the cost of the typical ICT fixture?
- How much could be saved if AOI and ICT were used as complementary tools, allowing a simplification of the ICT fixture?
- To what extent and for what products would it be possible to eliminate ICT altogether?
- Would the investment in AOI allow reductions in the capital equipment budget for electrical testing?

Additional questions may need to be raised as to the value of feedback on defects from AOI for immediate process improvements. Typically, contemporary quality monitoring software such as Orbotech's QPC tracks key parameters of production in real-time and provides valuable output for such analyses in the form of control charts, defect concentration diagrams and Pareto charts. What would the ability to provide process quality and capability data to a customer do for the ability of the company to attract more and more lucrative business, let alone new business from new sources?

Another Practical Case

The questions need to be answered in the context of a given manufacturer and are beyond the scope of this brief study. As for the cost of the typical bed-of-nails fixtures, one may want to revisit the case of a continental manufacturer (located in France) that produces auto radios and car navigation systems. At 50ppm or 1 reject per 20,000 products, the quality requirements are stringent, and a 100% test is performed at the end of a line. Typi-

Table 3 - Summary of cost saving

1. Elimination of Manual Inspection		108,000.00
2. Reduced Diagnostics Time		23,328.00
3. Elimination Of In Circuit Test		0.00
4. Simplification of In Circuit Test		0.00
5. Returns from Customer		75,000.00
Total Annual Savings	EURO	206,328.00

cally, this manufacturer has 50 fixtures built per year. Every fixture costs about 12,200 Euro. At this run rate, the manufacturer spends 610,000 Euro per year on ATE testing on a consumable item! Somehow it is very difficult to believe that a careful examination of the test requirements, of the actual defects and their distribution across specific assemblies would not lead to ways that would allow one to permanently reduce the cost of test, re-test and rework through the implementation of an AOI system.

The point should not be lost: ATE does not provide a permanent reduction in cost to the manufacturer nor does it provide a permanent increase in yields and quality. Only AOI as part of the production line and with the capability to monitor production as it happens can deliver that value. Operations that use AOI mainly as another gatekeeper actually fail to unlock the potential inherent in an intelligent implementation of AOI.

AOI: Only For High Labour Cost Areas?

Creating redundancies at ICT by means of implementing AOI is no chimera – even in low labour cost areas such as Eastern Europe. Recent tests showed that the process yield after post-solder AOI for a consumer product with some 450 components reaches a process yield of 98% - 99% within two weeks of implementation.

False alarm levels in ppm have been very low: 27 ppm based on the number of components, 13 ppm based on the number of positions (all IC pins are counted separately). With such results, it becomes clear that the manufacturer can plan on using one AOI in the line with one ICT – instead of two ICT testers, thus realising significant cost savings. The reduction in manual inspection and rework places would become an additional saving.

The cases, which have been outlined previously, have not focused at all on the reduction in field returns – which obviously depends on the value of the product manufactured. A calculation from a Nordic manufacturer bearing on the elimination of manual visual inspection and a reduction of field returns of 50% summarises the expected savings from implementing AOI in the Table 3.

Saving Coming From Field Returns

As one can see, in this case it has already been assumed that ICT may either become redundant or at least simplified, but the resulting savings have not been estimated. As seen earlier, the main savings come from the headcount reduction in MVI over a year with 48 workweeks, 3 shifts per day, 6 days per week, and a labour rate of 15 Euro per head.

The second main saving comes from field returns on a complex and high value product. The model then accounts only for savings that result from the reduced diagnostics time, i.e. the reduced actual time spent by a highly paid technician in FT on diagnosing problems when compared to AOI. The cost of re-testing and rework is not even considered here yet.

Pay Back Time Of AOI

While all situations are different and while one should not expect to find a formula that somehow fits all circumstance, it would appear reasonable to say that the pay back time for a high-end post-reflow solution today is between twelve to eighteen months – depending on the manufacturer, his environment and specific situation.

Given the permanent changes in the inspection and test strategy, it is also clear that AOI delivers obvious and permanent cost reductions by way of reducing personnel overhead, of reallocating personnel and engineering time to other issues, of reducing the costs of diagnosis, electrical test, rework and re-test, and of the potential of freeing capital for uses other than test as ATE is used more efficiently due to the improved yield downstream.

The Right Test And Inspection Strategy

Finally, as we have indicated earlier, a forward looking test and inspection strategy needs to get away from an approach which uses product specifications as the basis for setting inspection tolerances rather than process-based inspection limits. If the right analyses are performed with the appropriate SPC tools, then processes can be monitored continuously, and optimal inspection limits can be statistically calculated. In practice, this means that the inspection and repair process become more effective and cost-efficient since both false alarms as well as escape rates are minimised when inspection parameters are process-based.

Conclusion

Moreover, if close attention is paid to operating a process which uses machine and process capability assessment and monitoring tools (such as Orbotech's PC²M), then the cost-effectiveness of the SMT manufacturing process is significantly improved. Insofar as AOI performance is ultimately a function of the SMT process, the return on the investment in AOI is again affected positively.

In short, pay-back of less than one year is entirely feasible if the AOI strategy is thorough. Inspection pays if it ceases to be mere defect screening – and an EMS will benefit from the higher quality of its boards.

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