ELECTRONIC PRODUCT ASSEMBLY IN HIGH LABOR RATE MARKETS – A CASE STUDY IN EXPLOITING THE COUNTERWEIGHT TO LOW LABOR RATE COMPETITION: AUTOMATION

Tom Borkes
The Jefferson Project
Orlando, FL, USA
jeffer2@earthlink.net

ABSTRACT

At the conclusion of the 18th century, Thomas Jefferson contributed to the advancement of his first love, farming. He did this by designing a plow with a moldboard that optimized the plow's ability to help prepare the land for planting. His "mouldboard of least resistance" greatly reduced the energy needed to cut through, turn and displace the surface sod and soil to form a planting furrow. (Note: "mouldboard" and "plough" are British English spellings)

In both horse and human terms, Mr. Jefferson's invention significantly increased the productivity of those involved in the process of furrow or trench production – and, significant to this paper, the reduced *cost* associated with the increase in productivity was NOT achieved by finding a source of cheaper labor. At the time farmers in the South already had a source of cheap labor: a plantation's slave population. Primarily this group, along with several hired slave and free field laborers and overseers, combined to form the plantation's agricultural workforce. Guiding a horse-drawn plow was among the tasks associated with preparing, maintaining and harvesting the land to produce the farm's crop output. Annual output, however, was a function of planting cycles. With fixed resources and 5,000 acres to farm, Jefferson had a compelling interest to *get the crop in* as quickly as possible using the least amount of plantation resources. This would help produce the highest output per acre at the lowest possible cost.

Here in the 21st century, electronic product assemblers in high labor rate areas, whether they are original product developers (OPDs) or electronic manufacturing service (EMS) providers, continue to conclude that they cannot compete with operations in low labor rate regions of the world. These companies basically have the same objective as Jefferson: to produce the highest output at the lowest possible cost. They attempt to do this, primarily, by searching globally for the lowest labor rates to minimize cost. The harder way to reduce labor cost is to reduce labor *content*. This is what Mr. Jefferson's "mouldboard of least resistance" did. When attached to a plow it permitted the land to be prepared in less time with less resources – it reduced labor cost by reducing labor *content*, not labor *rate*.

This paper documents a real world project conducted to reduce the labor *content* of assembling an electronic product. In the project the OPD, who also does all the product assembly, tuning and test, is located in a high labor rate environment. Applying the latest available average loaded labor rates in high (US) and low (China) regions, the labor cost reduction realized by automating the assembly of two traditionally hand-soldered components resulted in a cost that is 6% less per circuit board (70% less than hand soldering in the U.S.)

The paper then conducts a return-on-capital investment (ROI) analysis to put the cost saving in a production volume payback context. This case study revealed a ROI of 2.67 months to generate enough cost savings to pay back the capital investment. Other factors such as process capability, control, variation and in-process yield are addressed as they apply to the assembly options for the components that were studied. In addition, *softer,* more difficult to measure process results, such how the automated process assembly affects fielded product quality and reliability, are discussed.

Finally, the labor cost reduction achieved by automating this portion of the product's assembly is addressed as a part of a much larger new paradigm-breaking general production model for high labor rate geographic regions. For example, it is observed that reducing labor content works at cross purposes with overhead-burdened operations that rely on direct labor hours to absorb those overhead costs. How does a high labor rate manufacturer reduce product assembly direct labor hours and reconcile all the indirect and overhead costs that need to be absorbed. The solution: drastically cut the indirect and overhead costs.

Key words: U.S. competitiveness, offshore manufacturing, Concurrent Education, electronic components

INTRODUCTION

Three papers have been written addressing the costs of electronic product assembly associated with high and low labor rate regions. [1,2,3] The papers codify the total cost of manufacturing electronic products by grouping specific cost elements into three categories: Labor, Material and Business Climate. Treating each cost category individually and then combining these costs resulted in the development of a revised high labor rate cost model. The new model demonstrates how it is possible to successfully compete against low labor rate operations. This paper applies the revised high labor rate model in the real world. It uses a case study to document the application of one of the important

conditions that the revised model is built upon: Reducing labor cost through the reduction of labor rate *content.* This is accomplished by exploiting the available automation, rather then focusing primarily on finding the lowest labor *rates*.

OF CABBAGES AND COMPUTERS

"Ploughing deep, your recipe for killing weeds, is also the recipe for almost every good thing in farming. The plough is to the farmer what the wand is to the sorcerer. Its effect is really like sorcery . . . . We now plough horizontally following the curvatures of the hills and hollows, on the dead level, however crooked the lines may be. Every furrow thus acts as a resevoir to receive and retain the waters, all of which go to the benefit of the growing plant, instead of running off into streams . . . . In point of beauty nothing can exceed that of the waving lines and rows winding along the face of the hills and vallies." [4]

In this response to a colleague's assertion that *ploughing deep* significantly reduces weeds, Thomas Jefferson in an almost poetic way demonstrates his excitement and enthusiasm for his preferred production *factory*: the farm.

Thomas Jefferson's *factory* in many ways was subject to the same competitive forces and general variables that confront our electronic product assembly factories in the 21st century –

<u>Factory output (dependent process variables) goal</u>

His: Maximize harvested crop output and yield, minimize cost

Ours: Maximize assembled electronic products and yield, minimize cost

<u>Basic factory process sequence</u>

His: Land prep > Plant > Manage > Harvest > Sell and Ship Surplus Produce

Ours: Procure parts > Assemble > Test > Ship Products

<u>Independent process variables</u>

(C=Controllable, U=Uncontrollable)

His: Affecting process capability and control
- Workforce skill level (e.g., plowmen, sowers, etc.) as it affects the depth and consistency of the furrows and sown seed (C)
- Equipment variation (C)
- Field contour and conditions (U)
- Climate: e.g., rain, sun, temperature (U)

Ours: Process capability and control
- Component and bare circuit board dimensional variation (C) (U) Consigned? or Purchased?
- Workforce skill level and variation in hand-soldered components (C)
- Variation in intermediate automated process steps results. This can be a result of equipment and material variation: paste, component placement (C)
- Degree of proactive process control (C)

<u>Competitive Forces</u>

His: Cost of produce, produce quality

Ours: Cost of products, time to deliver, quality and reliability of shipped product

Figure 1. Print Depicting 18th Century Field Plowing

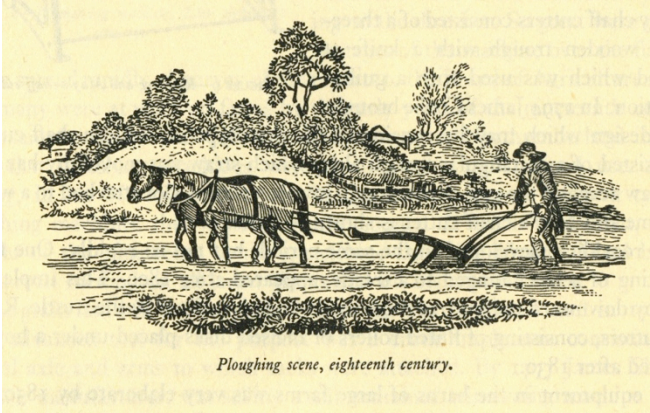


Figure 2. Typical Plow and Mouldboard

Figure 3. Detail of the Plow's Moldboard

Labor in Jefferson's *factory*

"Jefferson's slaves became accomplished plowmen (and women). They began their training early. Jefferson said that thirteen-year-old Robin 'works well at the plough already.' The Monticello harvest records indicate that the female farmworkers did some of the plowing. Jefferson's plan for the 1796 wheat harvest reserved eight laborers to 'keep half the ploughs agoing': Rachel, Mary, Nanny, Sally, Thamar, Iris, Scilla, and Phyllis. Jefferson wrote his overseer in 1818 that, 'when slack of work,' the female spinners 'might go to the plough.'" [5]

"The plough is to the farmer what the wand is to the sorcerer..." This quote contained in Jefferson's 1813 letter to C.W. Peale underscores the importance of a plough's efficiency to the economy of a nascent United States farming South. The South at the time had a growing slave population that was used for inexpensive, menial farm work.

Thomas Jefferson did detailed computations to determine the cost of plowing his plantations (See Table 1). He documented costs using a shorthand notation (e.g., *6-12-6* represented a cost of 6 pounds, 12 shillings and 6 pence; while, *1/3* signified a cost of 1 shilling, 3 pence). There are 20 shillings in a pound and 12 pence in a shilling. Therefore, from Table 1, the total average cost per day for a plowman is 1 shilling, 3 pence and for a horse is 1 shilling, 8 pence. Note that the horse cost more than the plowman! So, for a typical team of 2 horses, a plowman, and a plow, the cost per day is about 5 shillings. Taking inflation into account, 1 British pound in 1794 is equal to $134 USD today. So using Jefferson's calculation, one day of plowing costing 5 shillings (0.25 pounds) would cost $33.50 in today's U.S. dollars.

Table 1. Thomas Jefferson's Calculations on the Cost of a Plowing from His Farm Book [6]

a ploughman is worth.

his hire	£ 10-0-0
his clothes	2-0-0
his food	3-8-0
tools	1-0-0
overlooking	2-0-0
	18-8

divided on 300. working days is 1/3 a day.

a plough horse, lasting 6. years, is worth as follows.

his corn for a year	6-12-6
fodder	1-17-6
pasture	1- 0-0
	9-10
X^d by 6. years	57- 0
first cost	15- 0
3. years int.	2- 5
for 6. years	74- 5
for 1. year.	12-7-6

divided among 150. plough^g days is 1/8 a day

then a ploughman, 2 horses, & the plough cost 5/ a day, or by the acre and one half of that, to wit 2/6 the days the horses are idle, supposing them half fed, and the ploughman to be at work.

Figure 4. An Automated Circuit Board Assembly:
The Front End of an Electronic Product Assembly Line

Labor in an Electronic Product Assembly Factory: In the Beginning…

In the 1940s, the United States developed the critical need to produce high volume electronic products for the military. In addition, the accelerating post-war demand to serve a huge emerging consumer-based market created the need to produce electronic products in large quantities. The advent of the transistor and development of the integrated circuit required a means of interconnecting these *high density* devices and the other electronic components in an efficient and reliable way. This led to the invention of the printed circuit board. [7] The *Henry Ford* assembly line, used so successfully in the mass production of automobiles starting in the early 1900s, was applied to assemble high volume electronic products in a progressive fashion. The primary direct labor skill that was required was soldering. Soldering personnel (mostly women) could be hired at close to the federal minimum wage rate established in 1938. (Remember, this was the 1940s).

World War II produced an abundant, superbly trained domestic manufacturing workforce. As more sophisticated equipment was introduced into the assembly line, such as wave soldering in the 1950s, a gap began to form between operator skill and the skills needed to develop the process the operator was called upon to employ. A hierarchy of the manufacturing workforce developed as low wage equipment operators had to be supported by technicians, engineers, and equipment maintenance and repair personnel. Groups with niche skills developed as the assembly processes grew more complicated. Management, in their infinite wisdom, promoted this Balkanization of the workforce by grouping these narrow-skilled employees into departments. The operator/process gap grew exponentially in the early 1980s when surface mount component technology came roaring on the scene with its own set of new processes and equipment. Management continued to staff their operations with the lowest-wage personnel they could find, starting with the equipment operator. Rework and work-in-process (WIP) also grew exponentially. This was a function of batch processing and a reactive approach to process control. These practices could cause, in some cases, 100 circuit boards to contain the same manufacturing defect before it was discovered at test.

The Year the Manufacturing World Changed

Beginning in the early 1990s, EMS providers began to tap into a source of very low labor rate assembly: China (see Figure 5). Political changes occurred in China's communist government. The new leaders of the People's Republic of China recognized the power of free market capitalism to generate wealth. They decided to transition their *command* manufacturing economy from the total State control of the means of production, to a form of *State Capitalism*. This strategic change permitted companies from other countries to set up shop and take advantage of China's large reservoir of low cost labor. EMS providers saw this as a huge potential competitive edge in their supermarket-like battle to squeeze out additional tenths of a percent of margin in their two-percent margin world. Electronic product developers who manufactured their own products were quick to jump on the bandwagon. This scenario has been played out for most of history.

It is interesting to look at Japan's manufacturing output over time. Again, referring to Figure 5, note how from the early 1970s, Japan became a manufacturing juggernaut, generating a constantly increasing manufacturing output until 1995. In fact, in 1995 this country, with a population of about 125 million, almost matched the manufacturing output of the United States, with a population of over 266 million. Then, China entered the global marketplace and Japan's output immediately tumbled. The exodus in manufacturing to China continued globally, and in 2011 China became the world leader in manufacturing output. Many Pacific Rim countries followed as they offered OPD and EMS companies in high labor rate areas additional sources of low cost labor. Has there ever been a time where labor rate has not been prime factor in manufacturing success?

Higher Manufacturing Labor Rates = Higher Production of Exported Manufactured Goods?

It sounds counterintuitive, but in the early days of the Republic, "[the] primary reason for the rapid industrialization of the United States was very high labor costs…American wages were high because employers had to compete [for employees] with the exceptional opportunities of self-employment in order to attract adequate numbers of qualified workers." [8]

The same self-employment opportunities did not exist in England, "where the situation … was dramatically different. The average worker had little choice but to work for wages-whether as a hired hand farm laborer or as an industrialized worker. There were few new opportunities to become a merchant or even a skilled worker. Since the population was growing, there was at all times, a large available labor pool, albeit there was a constant emigration of the most ambitious to America. So, British employers could set wages very low and still attract the needed workers." [9]

Manufacturers in the Northern United States did not have the large slave population that developed in the South. The atrocity of slavery, while existing in the North in smaller numbers, was not suited for a labor force that needed to be trained with specific skills. These skills were required for the specialized manufacturing tasks needed to produce the region's goods and products. Leather goods like saddles, harnesses, buggy whips, and metal and wood products such as weapons and furniture required the skilled labor of artisans who typically worked there way up over the years from apprentice to journeyman to the owner of their own business. In a short time, the quantity of these types of goods -- not only for domestic consumption but also for export -- grew.

This manufacturing demand, while leading to more efficient processes, led to higher wages because of, as Alexander Hamilton said, "a scarcity of hands." Add to this, "Good farmland was so abundant and so cheap [compared to England] that even those who arrived in America without any funds could in several years, save enough to buy and stock a good farm." [10] So, the new nation had an ample and reasonably priced food supply. In addition, compared to Europe, taxes in America were very low and the people were not under the jackboot of a tyrant.

These conditions helped, but wages in America were still very high. "How could American manufacturing possibly compete on price [with England] given their far higher labor [rate] costs? Through better technology." [11]

Without an abundance of manufacturing labor, Americans desperately sought ways to increase worker productivity:
"For if workers equipped with a new technology could produce more than could the less mechanized workers in Britain and Europe, this reduced the relative cost of American labor *per item*. In this way TECHNOLOGY MADE IT IRRELEVANT THAT AMERICAN WORKERS WERE PAID, SAY, THREE TIMES AS MUCH AN HOUR AS BRITISH AND EUROPEAN WORKERS (my emphasis) … when American workers produced five or six times as much per hour, thus offsetting both their own higher wages and the capital investments in new technology …" [12]

The more things change from century to century the more they stay the same. The laws of economics and human nature are invariant – they are as true today as they were in the 18th century.

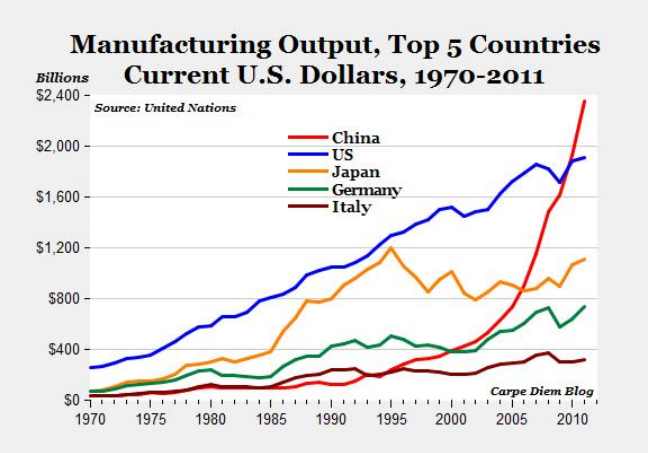
"British manufacturers were relatively reluctant to invest in new machines and processes because these increased their costs and cut into profits unless they also raised their prices. But Americans eagerly embraced promising new technology if they anticipated [that it would lead to] a sufficient increase in worker productivity." [13] Thus, the technology helped American companies deal with their scarcity of skilled manufacturing labor to meet the ever-increasing demand for goods and products – even though the employer had to pay significantly more for that labor.

Finally, "… American [manufacturing] workers were notable in another way. They were far better educated than workers anywhere else in the world (excluding Canada)." [14]
The dramatic shift in manufacturing output from Great Britain to the United States is documented in Table 2.

Table 2. The Changing Share of the World's Manufacturing Output (Source: League of Nations, 1945)

NATION	PERCENTAGE OF WORLD'S MANUFACTURING OUTPUT 1870	1900	1929
Great Britain	31.8	14.7	9.4
United States	23.3	35.3	42.2
Germany	13.2	15.9	11.6
France	10.3	6.4	6.6
Russia	3.7	5.0	4.3
Belgium	2.9	2.2	1.9
Italy	2.4	3.1	3.3
Canada	1.0	2.0	2.4
Sweden	0.4	1.1	1.0
India	–	1.1	1.2
Japan	–	0.6	2.5
Finland	–	0.3	0.4
Latin America	–	–	2.0
China	–	–	0.5
All others	11.0	12.3	10.7

Figure 5. The Changing Landscape of Global Manufacturing (Source: United Nations)



OF TURNIPS AND TABLETS: DIFFERENT *FACTORY*, SAME OBJECTIVE

Whether growing turnips or assembling tablets, the *manufacturing* goal is the same: develop a process with as wide a process window as possible, and keep the controllable variation that can affect the result inside the window – and reduce labor cost. The question is: How?

THOMAS JEFFERSON'S *MOULDBOARD OF LEAST RESISTANCE*: EQUIPING HIS FACTORY WITH A MORE COST EFFECTIVE PROCESS

"In a former letter to you I mentioned the construction of the mould board of a plough … many others have considered it with the same approbation [as you]. an experience of 5. years has enabled me to say it answers in practice to what it promises in theory." [15]

Figure 6. Thomas Jefferson's *Mouldboard of Least Resistance*
(Photo: Robert Llewellyn with my annotation)

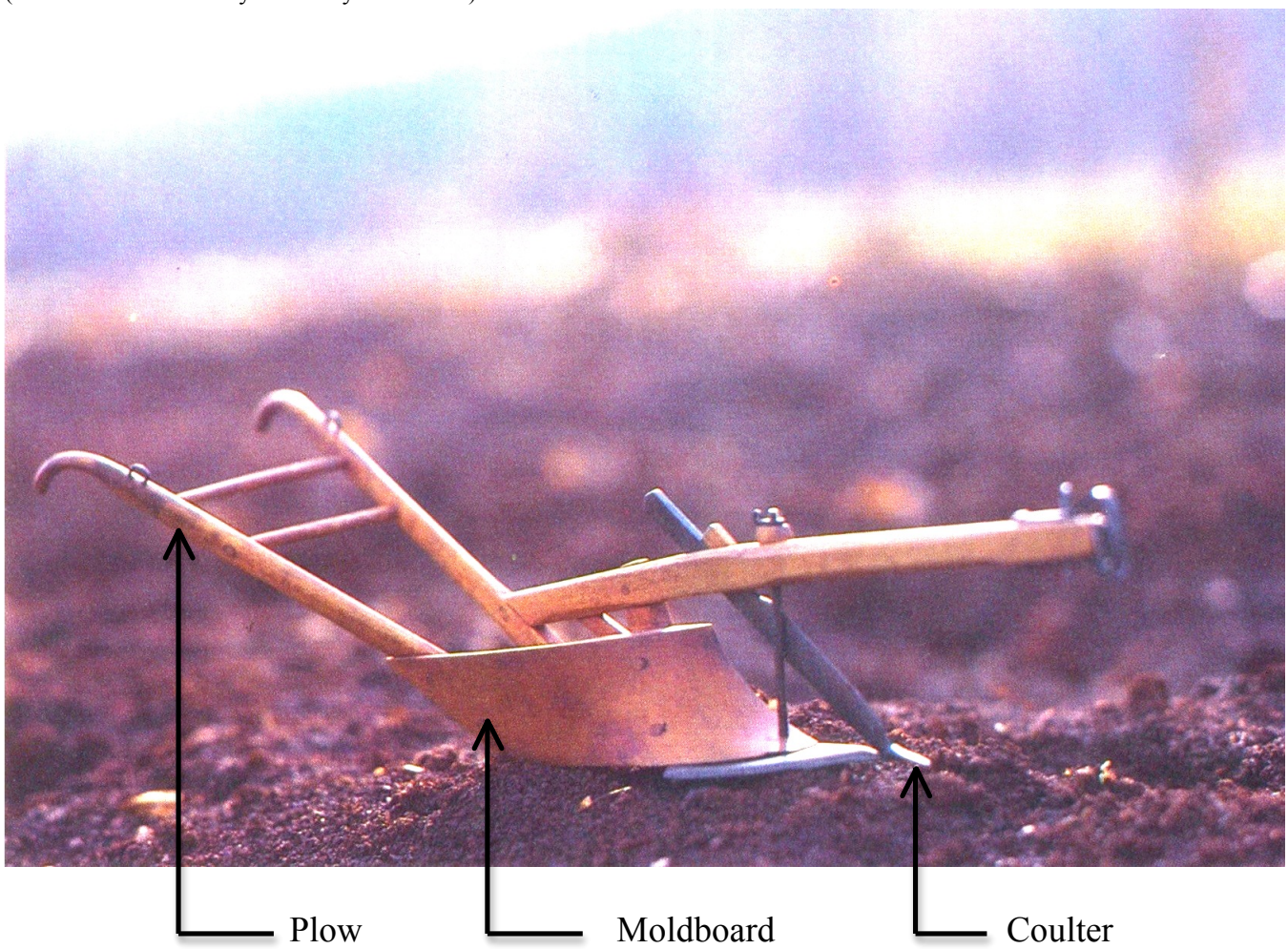


Figure 7. Close-up of Jefferson's Moldboard
(Photo: Robert Llewellyn)

His invention was received with acclaim in Europe. The British Board of Agriculture elected Jefferson to a foreign honorary membership in 1797 and the Parisian Society of Agriculture awarded him a gold medal in 1807.

Just as Jefferson's invention reduced the labor cost without reducing labor rate, automation can be used to reduce the labor cost of assembling an electronic product without a reduction in labor rates.

LIVING AND DYING WITH LOW LABOR RATES IN ELECTRONIC PRODUCT MANUFACTURERING

Companies whose manufacturing strategy and success are wedded exclusively to low labor rates find themselves in a never-ending, almost obsessive-compulsive operational mode. Anxiety, fear and uneasiness are accompanied by repetitive thoughts and obsessions related to an ever changing low labor rate landscape. This phobia has been manifested in the following way: After investing millions in China, rising labor rates are now cutting deeply into margins. If you are an EMS, the profit / loss line is already razor thin. [16] This doesn't consider the sinking feeling experienced when the true cost of doing manufacturing remotely hits the business leger. [17] Move to Vietnam, invest millions more and read, "Vietnam Loses Its Luster" [18]. Next stop: Cambodia? Is this anyway to run an electronic product assembly business – to have your competitive ability joined at the hip to a strategy you have little control over?

If you are in a high labor rate manufacturing environment, there are two primary reasons to manufacture remotely in a low labor rate manufacturing environment, i.e., out-border:

1. Your desire to sell your product into that country or nearby markets (a good reason).
2. You cannot compete on cost with a low labor rate country. (A reason that leads to the low labor rate chase described above and raises the question: Why are you unable to compete?)

If your reason for out-bordering is that you can't compete with operations in low labor rate regions, consider the following: The other way to reduce labor cost is to reduce labor content. This is discussed in detail in [19] and [20].

In summary, consider the following:

1. The ratio of the labor cost to the total product cost can be made relatively small through the development of high yield, automated assembly processes, coupled with severely reduced non-value added costs (e.g., indirect labor, overhead, G & A, ICT, rework, et al.).
2. When labor content is minimized, the effect on total cost by even a large manufacturing labor rate disparity approaches zero. Labor rate difference in many applications is shown to be a distraction, a red herring of sorts, cloaking the true root causes of non-competitiveness and masking an understanding of the total competitive landscape.
3. To achieve this level of labor cost reduction, certain conditions must be present. Several long-standing paradigms must be challenged and replaced with the following principles arrived at through common sense and out-of-the-box thinking:
   - The counterintuitive recognition that for automated, high-tech electronic product assembly it is more costly to hire low wage equipment operators than it is to hire multi-functional engineer who also act as operators.
   - Achieving true yield rates of 99.6% through the development and control of statistically capable processes by employing proactive techniques, rather than using traditional reactive strategies.
   - Utilizing continuous flow manufacturing (CFM) for ALL production applications. This means work-in-process (WIP) is minimized by pulling, not pushing, the product through the factory, and balancing product flow by knowing Takt times for all process steps.
   - Designing products that incorporate the principles of **DF MATERS:** (**D**)esign (**F**)or (**M**)anufacturing, (**A**)utomation, (**T**)est, (**E**)nvironment, (**R**)eliability and (**S**)erviceability). [21]
   - Having a multi-skilled workforce that has been taught manufacturing skills in the real world must be available. The long-term vehicle for developing this leading edge, world class workforce is a system of education that can fertilize, incubate and hatch this talent, allowing the graduate to hit the ground running.
4. The traditional hierarchical organizational model with its pyramid of people into groups, groups into sections, sections into departments, and collections of departments under a director, must be totally dismantled. Just two groups replace it: self-managed product teams, and a leadership group.

Also, those members of the church of the low labor rate maintain that high labor rate operations will be limited to low volume and prototype volume assembly, while high volume product assembly will always be more competitive in low labor rate environments. Shouldn't it be just the opposite? [22]

REDUCING LABOR COST THROUGH REDUCING LABOR CONTENT BY AUTOMATION: THE GREAT COUNTERWEIGHT TO LOW LABOR RATE COMPETITION

As discussed above, labor rates were much higher in 18th century America than England, yet the U.S. produced and exported manufactured goods in much higher quantities per capita. Worker productivity improvements made possible by exploiting the available technology were the reason.

A Case Study in Exploiting Automation to Reduce Labor Cost Through Reducing Labor Content - The Company:

The company where the study was conducted is an OPD that does their own manufacturing and product design. Their product requirements are considered high volume/high mix in the current domestic U.S. electronic product manufacturing industry.

The Case Study Product:
The products designed and manufactured are in the electronic communications industry sector. Of the many products that are produced at the manufacturing facility, the one chosen for the case study was an RF amplifier. The basic mechanical product design is a cast metal enclosure-mounted mother/daughter printed circuit board (PCB) assembly. The interconnecting between the mother and daughter PCBs is accomplished by using pins that are soldered to the daughter, or accessory, subassemblies, and then plugged into receptacles (sockets). These sockets are soldered to the motherboard during its assembly. Some of the plug-in accessory daughter boards are in their own molded plastic housings and accessible through the enclosure cover. See Figure 8. Other plug-in boards and leaded plug-in hybrid packages are located under the enclosure cover and are not visible in the photograph. There can be a total of over 15 plug-ins for a given amplifier product configuration. The product assembly also includes a discrete power supply PCB that is mounted in a compartment on the bottom-side of the cast enclosure. See Figure 9.

Figure 8. RF Amplifier
Photo Courtesy of Broadband International

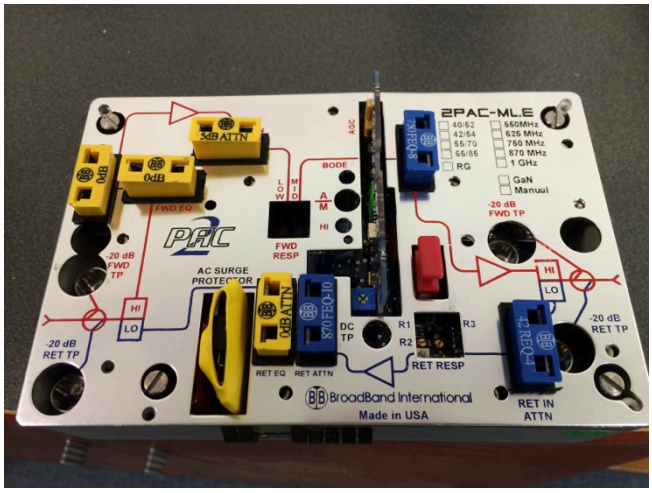
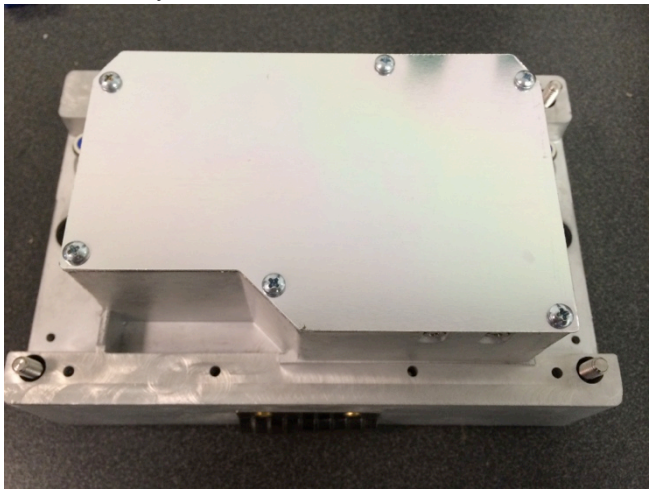


Figure 9. RF Amplifier (Bottom View)
Photo Courtesy of Broadband International



The Manufacturing and Labor Environment:
The manufacturing facility is in the U.S., a high labor rate environment with a relatively low EFW (Economic Freedom of the World) index and a high NOP (National Out-bordering Predisposition). [23]

The Basic PCB Assembly Process:
- Motherboard: 3-up panel of mixed (SMT and leaded) technology and hand soldering.
  - Mixed technology consists of automated SMT, hand insertion and wave soldering of leaded components
  - Hand soldering consisted of soldering sockets, coax cable and other miscellaneous components
- Daughter boards: Many-up (approx. 50-150 boards) - SMT and hand soldering.

The Labor Content Analysis
The analysis revealed that the largest opportunity to reduce assembly labor content was associated with the soldering of the receptacles (sockets). Soldering the sockets to the PCB is an electrical performance requirement because of the RF (high frequency) nature of the product.

Each 3-up PCB panel consists of 306 sockets, 243 large sockets for plug-in daughter PCBs, and 63 for leaded hybrid components (81 and 21, respectively, per board). See Figures 10, 11 and 12.

Labor Rate Determination
High Labor Rate (U.S.)
Assumptions (in USD):
1. Wage (earnings): $15.12/hr. [24]
2. Benefits are 32% of wages (earnings or raw labor rate: $4.84/hr.)
3. Employee Compensation (Earnings + Benefits) for U.S. manufacturing: $19.96 /hr.
4. Overhead rate for full labor burdening is 250% of wages (earnings or raw labor rate)
5. Benefit cost is included in overhead rate
6. All indirect labor is included in overhead rate
7. Overhead includes SG&A (sales, general and administrative costs – generally, a percentage of labor and material)
8. Overhead includes material handling, inspection and attrition (usually loaded as a percentage of the raw material cost)
9. Profit or fee is included in overhead rate to result in a fully burdened labor selling price
10. Assumptions 3 through 9 produce a fully burdened labor selling rate of $37.80/hr.

Low Labor Rate (China)
2012 Employee Compensation Rates for Manufacturing in China: Average in USD: $1.67/hr. [25]
Compensation is defined as whatever is paid to or for the workers in money or in kind according to relevant regulations, including:
- Wages
- Bonuses
- Free Medical Services
- Medicine

- Transport subsidies
- Social insurance
- Housing funding

With the weakening of the dollar, the willingness of the Chinese government to float their currency, and the continued upward labor cost pressure in urban centers, we will use an employee compensation rate of $4.00/hr. USD.

Assumptions: (in USD)

1. Employee Compensation (Earnings + Benefits) for China manufacturing: $1.67. As stated above, this analysis will use an employee compensation rate of $4.00.
2. An overhead rate of 300% will be used for full labor burdening and "reality" factor considerations.
3. Since it is difficult to know what part of the $4.00 compensation rate is raw labor and what part benefits, the entire compensation rate will be burdened with the 300% overhead rate
4. The overhead rate includes SG&A (sales, general and administrative costs – generally, a percentage of labor and material)
5. The overhead rate includes material handling, inspection and attrition (usually loaded as a percentage of the raw material cost)
6. Profit or fee is included in overhead rate to result in a fully burdened labor sell price
7. Assumptions 1 through 6 produce a fully burdened labor sell rate of US $12.00 / hr.

Labor Rate and Spread

The difference between fully burdened, high and low labor rate environments is $25.80 per hour.

Labor Content: Three Socket Process Options

A. **Hand Soldering:** Socket soldering was initially done by hand. An experienced soldering operator is able to insert and solder 10 sockets per minute. To solder all the sockets to a single motherboard takes about 10-minutes (30-minutes per panel). This represented about 40% of the total 25-minutes of labor needed to complete the board assembly. The additional labor needed for box assembly, tuning and testing is about 20 minutes.

B. **Automated Insertion and Reflow Soldering - 1**
A paste-in-hole solder printing process was developed to apply enough solder to fill the gap between the inserted socket barrel and finished hole in the PCB and to form good bottom side fillets. Since the panel is printed with paste for the SMT components anyway, there is no time or labor penalty for the paste-in-hole printing that is done for the sockets at the same time. The sockets were delivered to the placement / insertion machine on two tape and reel feeders, one for small hybrid socket, and the other for the large plug-in sockets.
The placement machine theoretically can insert sockets at the rate of 70 per minute. So, the 102

Figure 10. Small Hybrid Socket (left); Large Plug-in Accessory Socket (right) on a Jefferson Nickel

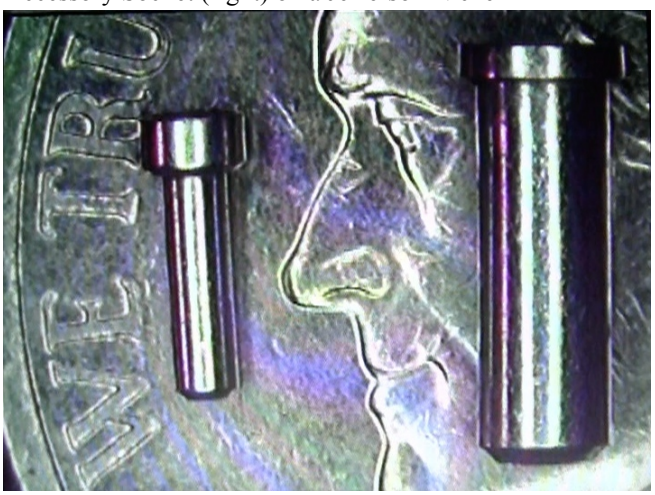


Figure 11. RF Amplifier Motherboard Panel (Bottom Side)

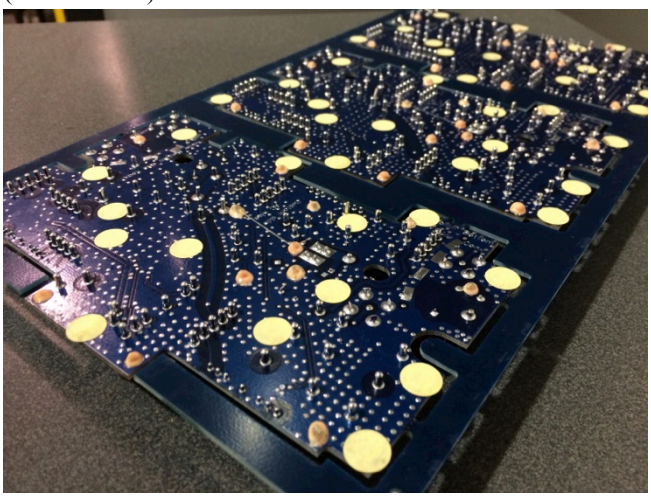
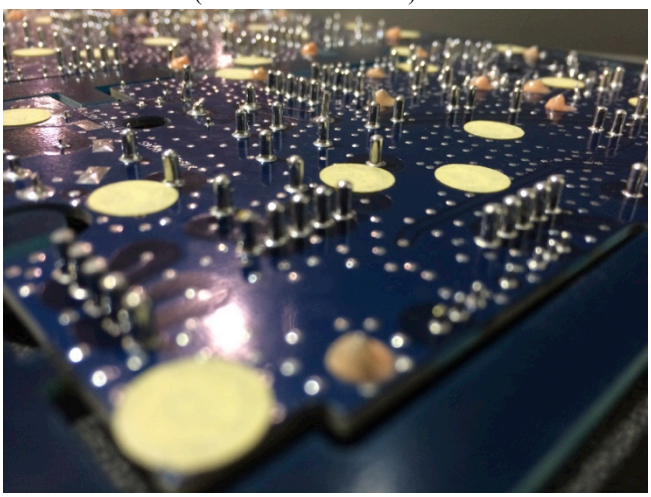


Figure 12. RF Amplifier Motherboard A *Sea* of Sockets (Bottom Side Detail)



sockets for one board should be inserted in 1.48 minutes (4.44 min. per panel) - if the machine doesn't reject any sockets. This was not the case.

Reliability of Socket Delivery by Tape and Reel
To minimize the volume of solder paste needed to be stencil printed, the difference between the socket barrel outer diameter and the finished hole diameter is nominally only 0.004 in. (0.1mm). To meet the required insertion accuracy requirement, the allowable variation in socket pick- up position on the nozzle is small. Therefore, a small window of acceptable x-y pick-up position is defined in the machine insertion / placement program. However, the embossed tape compartments allow significant socket movement. If a socket that is picked up from the tape by a nozzle falls outside the acceptance window, as identified by an upward looking camera, the part is automatically rejected to the dump bin and the pick-up is tried again. Figures 13 and 14 are photos of the machine display showing successive pick-ups and the typical variation from one pick-up to the next. After three unsuccessful attempts the machine stops and operator attention is required.

The motherboard also has 76 topside SMT components. Combined with the socket insertion, the theoretical Takt time at placement / insertion for a panel was 10.20 minutes (3.40 minutes per board).

Other Considerations with Sockets Delivered by Tape and Reel

- Because of the volume of large sockets inserted and the relatively small number of sockets on a reel, socket feeder changes are frequent
- Occasional tape jams
- There is less floor space is required than for hand soldering
- The cost of tape and the reeling sockets is significant to the total cost

The process issues identified above led to an average actual socket insertion time of 1.88 minutes per board (5.64 minutes per panel), an additional 0.4 minutes per board caused by tape and reel socket delivery. Adding the SMT component placement time, results in an average cycle time of 3.8 minutes per board (11.40 per panel)

C. Automated Insertion and Reflow Soldering – 2
The same paste-in-hole process was used. However, instead of tape and reel, two vibratory bowl feeders were used to deliver the sockets to the insertion machine pick-up point (See Figure 15) Initially, all automated placements and insertions were done on one machine. Figure 16 is a screen shot of the auto placement / insertion performance using the bowl feeders for the sockets. The mean build time for a *board* (3-up panel or array) was 544.3 sec. (9.07 min) or 3.02 min per motherboard. This represents a reduction in build time of 2.33 min. per panel (0.78 min per board) when compared to the process that delivers the sockets by tape and reel. Compared to the hand soldering process, the build time per panel is reduced by 20.93 min. per panel (6.98 min per board) - a reduction of over 69%.

Figure 13. Insertion Machine Upward Camera Photo of Socket on Vacuum Nozzle After Extraction From Tape

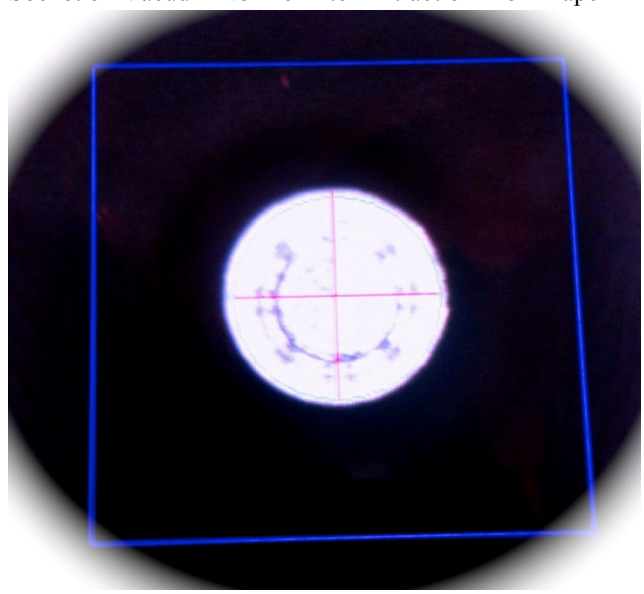
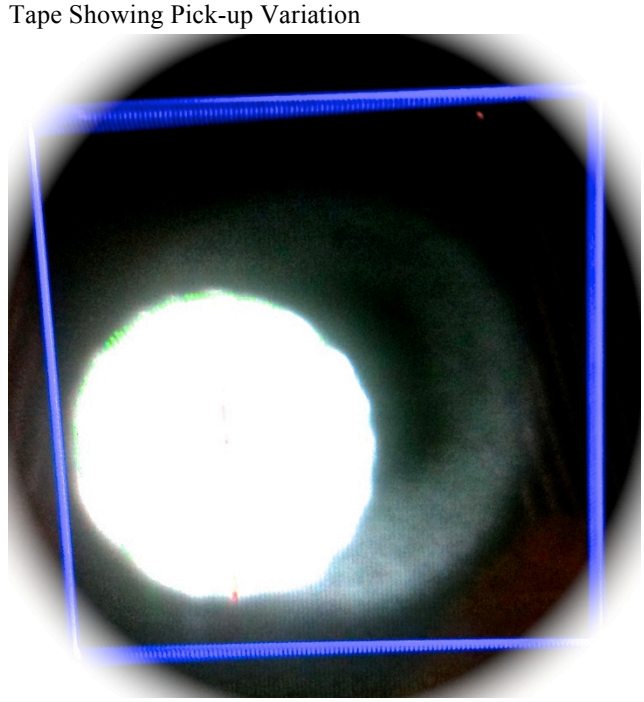


Figure 14. Insertion Machine Upward Camera Photo of Socket on Vacuum Nozzle After Next Extraction From Tape Showing Pick-up Variation



Reliability of Socket Delivery by Vibratory Bowl Feeders

Bowl feeding produced a better than five sigma (un-shifted) process (i.e., < 233 defects per million opportunities caused by the bowl). This was a significant improvement over sockets delivered by tape and reel. Why? The insertion machine relies on a socket pick-up point that has minimum variation. Unlike typical component placement tolerances that only require a part to be reasonable *placed* in the preprinted solder paste on the PCB pads, socket machine insertion requires smaller pick-up variation to ensure the barrel of the socket is successfully *inserted* into the finished hole in the PCB. There is no post pick-up correction for this variation by the insertion machine. The amount of pick-up variation is considerably more when the socket is delivered in an embossed, plastic tape (see Figures 13 and 14) than when delivered in by a bowl feeder shuttle/escapement (See Figure 17).

Figure 15. Vibratory Bowl Feeders for Large and Small Sockets Operating on the Insertion/Placement Machine

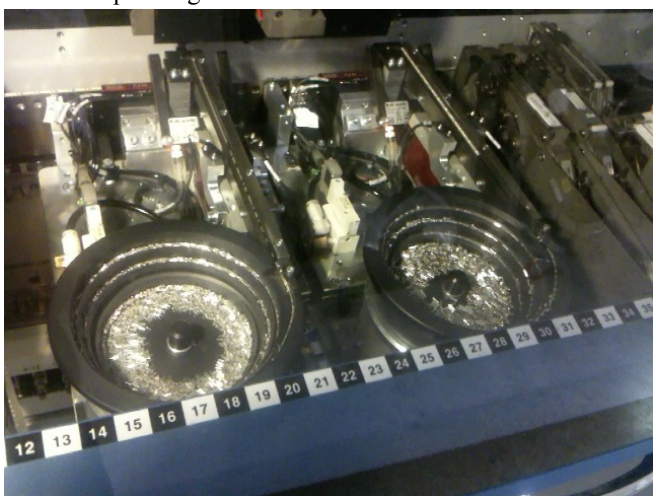


Figure 16. Machine Display of SMT Placement and Socket Insertion Performance for RF Amplifier Board All on One Machine Using Vibratory Bowl Feeders

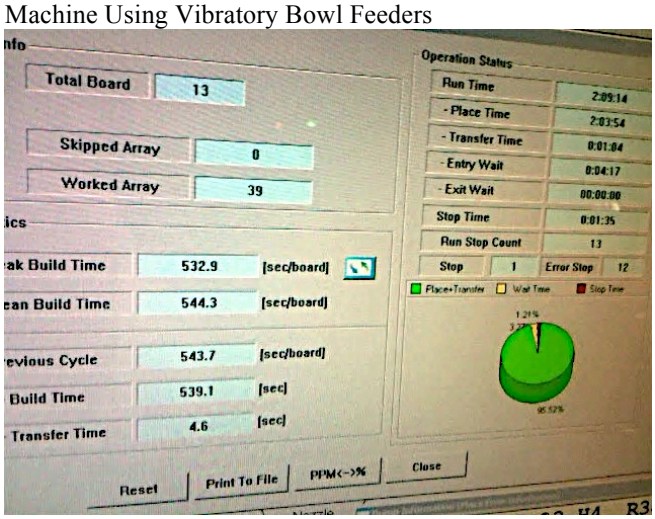
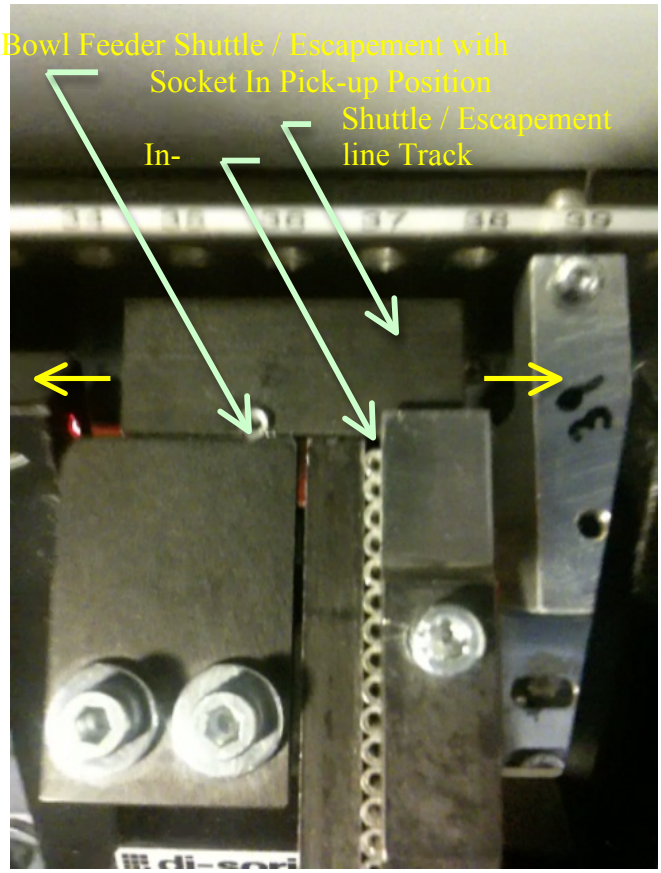


Figure 17. Vibratory Bowl Feeder In-line Track, Shuttle/Escapement, Pick-up Position Detail



The basic operation of the bowl is as follows: Loose sockets work their way up in a rotating bowl and are transferred to an in-line track. The track fills with a prescribed number of sockets determined by a photo detector placed upstream. At this point the bowl stops rotating. The shuttle / escapement receives a socket from the in-line track and moves (to the left as shown in Figure 17) to a pick-up point position that is established by a hard stop. The socket is removed from the shuttle / escapement by the insertion/placement machine as it would any component on tape and reel. Sensing the socket has been removed the shuttle/ escapement moves back to the in-line track and the process is repeated.

Other Considerations with Sockets Delivered by Vibratory Bowl Feeders

- There is less floor space is required than for hand soldering.
- Dumping the loose sockets in the bowls is significantly less expensive than having the sockets put on tape.
- Broken / bent sockets and debris in bowls will cause feeding jams
- Elimination of third party socket tape and reeling shortens the assembler's supply chain

- Board-to-board variability in solder volume and in board heating during soldering is less when printing and reflowing than when hand soldering. Although difficult to measure, this will result in longer fielded product MTBFs for the socket solder joints. This is because, statistically, the solder is exposed to lower process temperatures and the resulting solder joints have a finer grain structure with fewer grain boundaries.

Cost Analysis and Comparison

Table 3 applies the loaded high U.S. labor rate to the labor content of the three socket soldering options and compares it to the cost to solder the sockets by hand in China.

Table 3. Labor Cost Comparison Between China and the U.S. for Soldering a Quantity of 102 Receptacles (Sockets) into the RF Amplifier PCB

Socket Soldering Process	Labor Rate Area	Labor Content (Min./Hr.)	Fully Burdened Labor Rate (USD per Hr.)	Cost * (USD)
Hand	Low	10.2 / 0.17	12.00	2.04
Hand	High	10.2 / 0.17	37.80	6.45
Automated / Tape & Reel	High	3.80 / 0.06	37.80 + tape & reel cost of $0.035 per socket ($3.57 per board)	2.27 +3.57 5.84
Automated / Vibratory Bowl	High	3.02 / 0.05	37.80	1.90

* Includes 3rd party costs unique to process

Automating the socket insertion and making it a part of the SMT board assembly reduces the cost in the U.S. high labor rate environment. However, the cost of having to first put the sockets on tape and reel significantly reduces the cost savings of automating the process.

- Hand soldering the sockets in the U.S. costs 216% *more* than in China.
- Automating the soldering with the sockets delivered to the insertion machine on tape and reel costs 186% *more* than in China.
- Automating the soldering with the sockets delivered to the insertion machine by vibratory bowl feeders costs 70% *less* than hand soldering the sockets in the U.S.
- Automating the soldering with the sockets delivered to the insertion machine by vibratory bowl feeders costs 6% *less* than hand soldering the sockets in China.

Return on Capital Investment: **A Basic ROI Analysis**

To realize the cost saving associated with automating a soldering process that uses bowl-fed sockets, a capital investment must be made. The time it takes to receive a savings return equal to the cost of the capital investment is directly related to three basic factors:

1. The dollar cost of the investment to purchase the capital (bowl feeders) and the costs associated with the implementation the capital.
2. The average volume of amplifiers produced over time.
3. The cost savings per amplifier because of the use of the capital equipment.

Not considering tax implications and other financial factors (cost of investment dollars, etc.), a simple ROI for a U.S. produced, RF amplifier board, using the automated bowl-fed socket soldering process is as follows (estimated in USD):

- Cost of bowls: two, at $20,000 each = $40,000
- Amplifiers produced per year = 10,000 units
- Cost saving per unit compared to:
  1. Hand soldering in U.S. = $4.55
  2. Automated soldering with sockets on tape and reel = $3.94

Therefore, the ROI for purchasing bowl feeders to automate the socket soldering process for building 10,000 RF amplifier boards per year versus:

1. U.S. hand soldering – the investment is paid back after building 8,791 boards, or in about 10.5 months.
2. U.S. automated assembly with sockets on tape and reel – the investment is paid back after building 10,152 boards, or in about 12.2 months.

This would be the ROI if the product used in this case study was the only one that utilized the automated, bowl-fed socket process. It's not.

A more accurate ROI would be to consider the total number of the two sockets that are inserted and soldered on all products over a year. This estimate is four million sockets.

On a per socket basis, the cost savings are as follows (divide the cost savings per RF amplifier board by 102 sockets per board). Cost saving per socket using the automated bowl feeders compared to:

1. Hand soldering in U.S. = $0.045 per socket
2. Automated soldering with sockets on tape and reel = $0.039 per socket

Therefore, the ROI for purchasing bowl feeders to automate the soldering process for 4 million sockets per year versus:

1. U.S. hand soldering – the investment is paid back after soldering: 888,889 sockets, or in 2.67 months.
2. U.S. automated assembly with sockets on tape and reel – the investment is paid back after soldering 1,025,641 sockets or in 3.08 months.

What about using the automated process with bowl-fed sockets versus soldering by hand in China?

- Cost savings = 0.0014 per socket
- The ROI assuming 4 million sockets soldered per year: Investment is returned after soldering 28,571,430 sockets or in 7.14 years.

This is a long time for to wait for a $40,000 investment payback. But, are we comparing apples to oranges?

DISCUSSION OF RESULTS

Using vibratory bowl feeders to insert the 102 sockets per board and soldering them along with the other SMT components, results in a labor cost that is less than the cost of sockets that are hand soldering in a low labor rate environment. An ROI analysis shows a very rapid return on the necessary capital investment when the labor saving from the bowl feeders, compared to the other high labor rate soldering process options, is multiplied by the socket usage.

Is the final ROI calculation significant – 7.14 years to payback the investment for bowl feeders? The bowl feeders' labor cost in a high labor rate environment when compared to hand soldering in a low labor rate environment produces a long investment payback. However, this is not the point. The point is that through automation, a high labor rate can be made competitive with a low labor rate environment. If an assembly operation is in a high labor region, to decide to out-border to a low labor rate assembly source, instead of building on-shore, is a much more involved decision than analyzing the ROI for the automation of soldering sockets. Many other criteria enter the decision-making process. It would be like saying "I will build my products in South Africa because it has the cheapest price for electricity in the world." It may be that South Africa would be a great place to build electronic products – but not exclusively because power is the least expensive in the world. Power cost is but one small piece of multi-piece puzzle. Other factors in other parts of the world are other "pieces" -- factors such as the logistics challenges of what will probably be a very stretched supply chain, complications in new product introductions, intellectual property security, variation in quality due to variation in manual process, disruptions in production due to political unrest, and the list goes on.

CONCLUSION

An Early Example of Exploiting the Technology to Reduce Labor Content and Cost

In April 1790. President George Washington signed a bill that authorized the formation of the U.S. Patent office. As Secretary of State, Thomas Jefferson became the Patent Office's first examiner. It is interesting to note that when Jefferson invented his "mouldboard of least resistance," and mathematically documented it in 1794, he did not apply for a patent, even though it was accepted with wide acclaim. There may have been two reasons for this:

1. Jefferson's overriding interest in the development and survival of his infant country. Leaving his valuable invention unpatented provided his countrymen with unencumbered access to a means of increasing the nation's food supply and improving the country's farming financial performance. This, in turn, in a small way strengthened the young nation's economy and helped give it the roots it needed to survive and grow. History shows Jefferson's unwavering dedication to the importance of individual freedom. The new country was built on this cornerstone. He saw this freedom not only benefitting his own country but also acting as a beacon to the rest of the world. "All eyes are opened, or opening to the rights of man." [26] Survival of his country would ensure this beacon would not be extinguished.
2. A perceived conflict of interest since he would be evaluating his own invention for its patent worthiness.

Regardless, Jefferson, in perhaps a small way, was one of the first to provide a means to reduce "product" cost by exploiting the technology, a technology he developed on mathematical principles.

Total Product Cost is a Sum of its Parts

The point of this case study has been to evaluate whether exploiting automation can be an effective counterweight to low labor rates. This study has shown that it can be for this application: The cost to solder two components on a circuit board that represents a significant percentage of labor content is less expensive in a high labor rate area using automation than in a low labor rate region using manual labor. This is significant in the battle against those who obsessively belong to the church of low labor rate, but it is only a part of the story. When examining the complicated out-bordering "mosaic," all of the "tiles" must be known, understood and considered.

The "Value" of High Direct Labor Rates?

High direct labor rates can lead to high labor costs that, in turn, lead to high product costs. This usually results in an assembly operation that finds it difficult to compete. Reducing labor content as demonstrated by the case study described in this paper can be an effective tool in reducing direct labor cost in high direct labor rate environments. Ironically, in many cases, this can cause a problem. Direct labor hours are loaded up with indirect, overhead and G&A and any other non-product related costs the company pays for. This results in the labor sell rate. Sell enough labor hours at this rate and the overhead costs are paid for. However, the fewer direct labor hours into which these costs can be absorbed, the higher loaded labor rate will be. [27] The answer is that in concert with reducing labor content, indirect and overhead costs must be reduced as well. [28]

Automation can be an effective counterweight to high labor rates, but recognize it for what it is: only one tool of many that is needed to reduce product cost.

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