"… LIKE HOLDING THE WOLF BY THE EARS …"

THE KEY TO REGAINING ELECTRONIC PRODUCTION MARKET SHARE: BREAKING FREE OF THE DIVISION OF LABOR MANUFACTURING MODEL IN HIGH LABOR COST GLOBAL REGIONS

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ABSTRACT

Thomas Jefferson foreshadowed the American Civil War by almost 80 years when, in 1782, he said, "I tremble for my country when I reflect that God is just (and) that his justice cannot sleep forever…" In 1820, Mr. Jefferson likened slavery to holding a "wolf by the ears" – having the fear of letting go, but knowing one cannot hold on forever.

This paper uses the powerful *wolf by the ears* metaphor to address the dilemma faced by companies in high labor cost regions of the world – *holding on* for dear life to the notion that securing the lowest hourly labor rate for their production workforce is the necessary cornerstone to constructing a competitive electronic product assembly operation. Even though they may sense there is another way, the disciples of this model are obsessed with following low labor rates around the world, *afraid to put it down,* and fully embrace the other (albeit harder) ways to decrease labor cost – first, by reducing labor hour content through truly exploiting the available automation; and second, through a dramatic reduction in overhead cost.

The paper maintains that there are only two reasons for manufacturing in low cost labor areas: selling your products into those markets (a good reason), and being *unable* to successfully exploit the available automation, coupled with having an excessive overhead structure that is bloated with non-value-added indirect costs (a bad reason). These added costs must be absorbed by the direct labor. However, absorbing them drives the fully burdened labor sell rate well above the level that can compete with manufacturers in low cost areas.

The second reason is not easy to address. It is easier and safer to cling to our traditional production model and exert most of our energy in searching for and developing sources of cheap labor, often to compensate for inadequate automated processes that lack the proper proactive process controls to head off assembly defects before they occur.

This paper offers an alternate electronic product assembly model for high cost labor regions, looking at assembly labor in a totally different way. It requires breaking with the traditional hierarchical organizational structure, a paradigm that is the legacy of the Henry Ford division of labor model.

The new strategy has three basic elements:

1. *Transformation of the direct labor workforce*. In this new model, the approach to direct assembly labor is turned upside down from the way we have traditionally looked at it. We currently staff with a large number of the lowest cost "unskilled" production line workers and equipment operators we can find, and then create tiers of support groups – material procurement, incoming inspection, kit/prep and equipment set-up personnel; equipment repair technicians; test, rework and final assembly operators; process, quality and test engineers, etc. These personnel are then organized into departments, each with supervisors and managers, and the departments are organized into groups, each with its own director. In this traditional corporate pyramid, only a portion of the cost of this massive workforce is direct labor. Yet, it is this direct labor that must absorb all the layers of indirect and overhead costs, resulting in labor sell rates of $50.00 per hour and higher. And, when business bookings go away because of poor planning by management and leadership – who are included in the overhead cost category – it is the direct labor that always seems to get cut first. Go figure!

But, of course, the reason for the dilemma is *never* the overhead contributors' performance – "It's the $0.75 per hour labor we have to compete against. Let's find a source of cheaper direct labor!" This paper suggests a better way to compete with low labor rate regions: exploit the competitive potential of the available true (not faux) automation that is built on capable and controllable processes [1]. This requires products that are designed for automation. It also requires a more highly skilled, more expensive labor force to replace the labor-intensive workforce. While increasing the cost per labor hour, this model reduces the labor hour content. This results in a less expensive overall cost of labor.

The paper encourages the emergence of the *super engineer,* a multi-skilled professional. Not a mechanical engineer or test engineer or process engineer; rather an engineer capable of handling all engineering aspects of high tech automated electronic assembly. But, alas, this is not enough, and leads to the next element in the new model.

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2. *A corporate model that focuses on the assembly of the customers' products and not on technical disciplines or departments within the organization*. A radical flattening and restructuring of the traditional manufacturing organization, a vestige of the Henry Ford division of labor and assembly line model, is implemented to significantly reduce the overhead that the direct labor has been called upon to absorb. The new model replaces all departments and their management by just two groups: small, cross-skilled product teams and a leadership group. The leadership group serves the product team as an enabling function, providing the team with the skill sets and tools they require for success. The paper concludes with the final element of new model.

3. *Creating an educational environment that serves the needs of the new model.* With an operational organization consisting of a small number of almost all multi-disciplined engineers, a holistic and practical approach to engineering education is required to create a workforce that is intelligent, well-rounded and real-world based – one with exceptional critical thinking, problem solving and team oriented skills – one that is well versed in the physics, process, price and politics involved in successfully assembling high tech electronic products. The paper suggests that an educational framework built on the principles of Concurrent Education [2] would provide these skill set requirements.

Key words: US competitiveness, offshore manufacturing, Concurrent Education

INTRODUCTION

Often in business, or even in life, the dark cloud of adversity can have a silver lining. The dramatic loss of market share to Japanese automobile manufacturers that started in the 1970s compelled the U.S. to take a hard look at the way they produced automobiles. If it weren't for this *motivation*, odds are the traditional manufacturers would have continued to *hang on* to designing and putting cars together in much the same way as they always had done – perhaps nibbling away at the status quo with the productivity improvements new automation technologies continued to offer. The question this paper asks is whether the exodus of electronic product assembly that we have witnessed from high to low labor rate global locations is inevitable. If not, how can it be stopped and reversed? Can it be done by nibbling away at it? Can it be done simply by moving toward the light that this year's new trademarked buzz phrase shines on the industry? Or, is a massive rethinking and reconstructing of the way we approach electronic product assembly the only possible way back to expanding market share?

What do Thomas Jefferson and high tech electronic product assembly have in common? It would seem that they are strange bedfellows to say the least. While even his harshest critics have recognized this man's incredible intellect, what possible advice can the Sage of Monticello, whose life spanned the 18th and 19th centuries, offer to help us navigate the treacherous waters of competing in the global economy of the 21st Century? Politically, just about every group seems to want to claim this Man for All Seasons as their own. Whether Conservative or Liberal, Independent or Libertarian, all find a philosophical mooring in Mr. Jefferson's tenets on the value of the individual and the optimal relationship between those individuals and their government. But, as a source for a strategy to regain electronic production market share in high labor cost markets, Jeffersonian philosophy seems like a tortured stretch, at best.

This paper begins with the intuitive premise that in today's global economy, electronic product assembly MUST be done in a low hourly labor rate environment to successfully compete. This *null hypothesis* is supported by the striking relative labor rates in low and high labor regions. It is also supported by people like the highly respected Thomas Friedman, whose book *The World is Flat* [3], has taken on an almost mystical quality in many circles, revered as the new, one world economic bible.

Is it possible for an organization to competitively assemble products in a high labor cost environment? This paper submits that it is, if we are willing to take a longer view on what we are doing and take the time to think beyond simply meeting this quarter's *numbers*. John Kotter of the Harvard Business School would call this the difference between managing and leading [4]. Also, we need to think way outside the box by examining some paradigms that take time and thought to challenge and finally, after this, find the courage to overcome the fear and pride associated with these *wolves*, and *let go.*

HOW WE GOT HERE: A BRIEF HISTORY OF THE DIVISION OF LABOR ORGANIZATIONAL MODEL

Providing goods or services for which someone else is willing to pay: This is the marketplace. Once a person's basic needs are met and they are governed by a system that secures an individual's natural right of freedom to contract (the right to enter into private business relationships with other individuals), they have the opportunity to offer their surplus labor to others for compensation. That surplus labor can take the form of growing crops, manufacturing products, or providing services. In any case, the output is subject to the laws of economics. The most basic is the law of supply and demand. In addition, the availability of capital leads to the formation of private businesses that can produce large volumes of products by collecting the appropriate people and equipment into one place. The modern factory system was being born in England just as 13 colonies in The New World were beginning to question the policies of Parliament and King George III. This new factory system arose out of what the history books call the Industrial

Revolution. Once the number of employees and different areas of specialization within the company began to increase, it became necessary to plan and coordinate the individuals' activities. It made sense to organize people of like skills together into specialized departments and have their activities directed by a manager with the same skill. The relationship of labor and management, sometimes called labor and capital or the worker and business owner, is in constant debate and tension. From Adam Smith to Karl Marx, theories abound regarding the optimal form for this relationship and the further relationship between a society's means of production and its government. Practically, this paper addresses the labor/management relationship as seen only from the perspective of competitive cost. There is, however, value in understanding at least the historical context under which the current high labor cost factory model developed before we go about dismantling it.

As president in 1803, Thomas Jefferson doubled the size of the United States when he purchased the Louisiana territory from France's cash-strapped Napoleon. A Virginian and a farmer, Mr. Jefferson recognized the immensity of the country and had a strong opinion on how the ever-increasing American population should grow to fill it. With all this land, Mr. Jefferson saw agriculture as the primary source of his country's happiness and sanguinity: "Agriculture... is our wisest pursuit, because it will in the end contribute most to real wealth, good morals and happiness." – *Thomas Jefferson to George Washington, 1787.* And, as a means to develop responsible citizens: "Cultivators of the earth are the most valuable citizens. They are the most vigorous, the most independent, the most virtuous, and they are tied to their country and wedded to its liberty and interests by the most lasting bonds. As long, therefore, as they can find employment in this line, I would not convert them into mariners, artisans, or anything else." *Thomas Jefferson to John Jay, 1785.*

In Mr. Jefferson's eyes, a crowded city like London with its polluted condition and inhumane industry was a source of disease, oppression and corruption: "I view great cities as pestilential to the morals, the health and the liberties of man. True, they nourish some of the elegant arts; but the useful ones can thrive elsewhere; and less perfection in the others, with more health, virtue and freedom, would be my choice." – *Thomas Jefferson to Benjamin Rush, 1800*. Because of its concentration of cheap labor, the city became home to the high volume manufacturing that grew out of the industrial revolution: "I consider the class of artificers [i.e., manufacturers] as the panderers of vice and the instruments by which the liberties of a country are generally overturned." – *Thomas Jefferson to John Jay, 1785*. Ironic, of course, because Jefferson had his own source of cheap labor – over 200 human beings in the bondage of slavery.

In his introduction to Emile Dukheim's *The Division of Labor in Society*, Lewis Coser notes that Adam Smith, a contemporary of Jefferson, great economist, and author of *Wealth of Nations*, was: "basically optimistic about the benefits the new mode of production (the division of labor) would bring [5]. Smith believed that vastly increased productive capacities would raise the level of human happiness to previously undreamed degrees. However, according to Coser, Smith echoed Jefferson's concern: "How could one expect over-specialized workers to develop a sense of citizenship and a devotion to the common weal (public good)?" [6]

In his later years, Jefferson tempered his negative view of industrialization as it became apparent that the greater good of the population and the overall prosperity of the country were being served by the growing manufacturing industry. And besides, people had the choice to participate in that lifestyle if it was consistent with the pursuit of their own and their family's happiness, as guaranteed by the inalienable rights with which each individual was endowed, i.e., "… with certain unalienable (sic) Rights, that among these rights are Life, Liberty and the pursuit of Happiness." – *The Declaration of Independence, Thomas Jefferson, 1776.*

Of Buggy Whips and Automobiles

"My kingdom for a horse!" screams a desperate Richard III during his battle on Bosworth Field in England. This quote is from William Shakespeare's interpretation of this historical event that occurred in 1485. The battle resulted in the ambitious, ruthless and disfigured Richard and his Plantagenet house being replaced by the Tudor dynasty. Horses were valuable, no, invaluable in the 15th century. However, they were expensive and scarce, so only a select handful of the nobility, knights and other privileged combatants were able to take them onto the field of battle. The common soldiers walked with poles, pikes, axes, or spears in hand.

The horse as the primarily mode of rapid transport remained valuable through the end of the 19th century. But, typically, people did not ride bareback. Saddles, carriages, buggy whips and other accoutrements used in association with the horse transport industry were invented. People with the right skills, both manufacturing and economic, opened businesses to make and sell these products. Those that provided the most value in their products (most desired features at the best price) sold a lot. Those that didn't dropped their price or looked for something else to do. Governments at that time weren't in the bale-out business and, besides, horse stalls always needed cleaning. Hence, the craftsman, a person with unique training and skills, began to emerge to meet this product demand. Blacksmiths, wheelwrights, saddle makers, leather craftsmen and buggy whip makers were all occupations that were created or expanded to serve the horse transportation industry.

Then, the relatively new "horseless carriage" met Henry Ford's assembly line – effectively making the automobile available to the masses – marking the end to the huge demand for the buggy whip.

A shift had occurred in the way people thought about their personal mode of transportation. Westfield, Massachusetts, is nicknamed "whip city." Before the mass-produced automobile came along, there were close to 60 factories that manufactured buggy whips in Westfield alone. Today, one remains.

Of course, the buggy whip maker is just one of the occupations that have bit the dust, so to speak. The following is a list of some other jobs that were once ubiquitous:

1. Television repair man
2. The milk delivery man
3. The photographic film processor
4. Vinyl audio record presser
5. Coal and ice delivery men

All of these occupations have virtually disappeared as the demand, distribution or technology associated with their products has plummeted or has been transformed.

Over the years, the electronic product assembly industry has run through a seemingly endless number of buzzwords and phrases. High paid consultants have promised the production panacea leading to a high tech electronic assembly nirvana. The *elixir du jour* has run the gamut from *total quality control* to *lot size one* to *flexible manufacturing*, to *six sigma* to *just-in-time* to *kaizen* to *poka yoke* to *lean manufacturing*. All of which, without question, have good attributes. However, even with all these tools in the toolbox, high cost labor hour operations have not been able to compete with their low cost labor hour counterparts. The intuitive conclusion seems be that, in order to compete, our electronic products must be assembled in the lowest cost labor hour environment possible. It seems that the ability to make a sophisticated DVD player in a low cost labor hour region, sell it for $50.00 and make a profit reinforces the intuition – Q.E.D. So, if there is an alternate, perhaps industry has to dig deeper into its production tradition, a tradition whose basic paradigms and assumptions have gone largely unchallenged. Therefore, these businesses must seek another path to competitive success.

In 1908, Henry Ford utilized to the extreme the efficiencies offered by the division of labor manufacturing strategy. He not only divided the labor-intensive assembly of his Model T automobile into a sequence of small process steps, each step having a dedicated person repeating the same step, he kept the person stationary and moved the work by the assembly operators. Although Ford is generally credited with perfecting the assembly line, slaughterhouses in Chicago used the idea sixty years before to *process* cows, *mooving* them to the ultimate carnivore more rapidly. Job repetition became the emerging time and motion specialist's best friend.

Rules To Live (Assemble?) By

Jefferson died on the morning of July 4, 1826 at the age of 83. His founding brother, sometimes great friend and most times fierce political rival, John Adams, died that afternoon, exactly 50 years to the day that they, along with 54 other founding brothers, adopted Jefferson's Declaration of Independence. Near the end of his remarkably long life for that time, Mr. Jefferson offered ten general rules to live by:

1. *Never put off until tomorrow what you can do today.*
2. *Never trouble another for what you can do yourself.*
3. *Never spend money before you have earned it.*
4. *Never buy what you don't want because it is cheap.*
5. *Pride costs more than hunger, thirst and cold.*
6. *We seldom repent of having eaten too little.*
7. *Nothing is troublesome that we do willingly.*
8. *How much pain the evils cost us that never happened.*
9. *Take things away by the smooth handle.*
10. *When angry, count to ten before you speak; if very angry, count to a hundred.*

The first precept has relevance to this topic: *Never put off until tomorrow what you can do today.* Making a decision not to take action on a critical issue has several possible bases:

1. Laziness
2. Lack of motivation
3. Pre-occupation
4. Fear (self-preservation)
5. Bad judgment
6. Stupidity and/or ignorance.

And, when one finally does something, the cause of *not* doing the best thing has similar possible causes:

1. Near-term survival (Fear)
2. Ignorance and/or stupidity
3. Short-term thinking
4. Having more unknowns than equations (poor judgment).

The other rule that applies to the topic of electronic product assembly is number five: *Pride costs more than hunger, thirst and cold.*

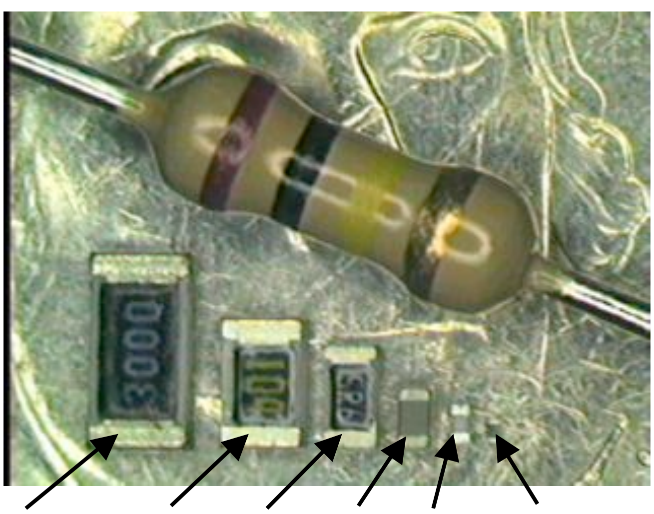
The Price of Pride

Starting in the late 1940s, W. Edwards Deming was assisting the Japanese in rebuilding their post-war manufacturing capability. At that time U.S. manufacturers were neither interested nor motivated to having their way of manufacturing challenged. Telling Detroit (for all intents and purposes the only game in town) that there was a better way to make automobiles was not what the prideful executives of one of the major manufacturers wanted to hear. Maybe the reaction went something like: "This guy has the audacity to tell us that we are chained to the anchor of the past – that our quality assurance methods are inadequate and our products do not embody the value that our customers are demanding," or something like that. When American consumers started demanding that the American cars they purchased had Japanese-made transmissions built into them rather than the failure-prone American transmissions, attention began to be paid.

In 1981, the Ford Motor Company invited Dr. Deming to help them understand the problem they were having competing with the Japanese. They were shocked when he advised them that the problem had much more to do with the behavior and philosophy of their management personnel than with their product quality assurance techniques. Eighty-five percent of Ford's problems in developing better cars, he said, had to do with management, not production!

The State of Electronic Product Assembly and Human Nature

Assembly processes for electronic products have changed significantly since the emergence of the vacuum tube and the printed circuit board [7]. The scaling down of component size through integrated circuits and surface mount packaging technology has taken away the choice of building by hand or building by automation (Figure 1). The requirement to repeatedly apply solder paste (instead of hand soldering) and the inability to manually handle discrete packages such as the 0201 [8] and 01005 [9] have required robots to replace hand assembly. Of course, beyond the handling issues, the ability in high labor rate markets to reduce labor cost through automation is the driving force to move from manual to automated assembly.



1206 0805 0603 0402 0201 01005
(English Designations)

Figure 1. Passive SMT Component Family & Their Patriarch: The Axial-leaded Resistor
(All on a Jefferson Nickel)

With these requirements comes the need to develop a capable process for the automation. A process window must be developed that is wide enough to contain the natural variation that will occur over time in the process variables. To do this successfully for automation, the physics that underlies the process and the equipment that conducts the process must be well understood. Hand inserting and hand soldering the two leads of an axial leaded resistor to a circuit board might take 30 seconds of labor. Having a high speed robot place an SMT resistor in solder paste that was printed by machine, and then melt the solder in a reflow oven, might take 0.1 seconds when processed with the rest of the components on the circuit board – and, the raw labor cost for this operation, if the board is handled by machine and travels on automated conveyors, is $0.00! This is only true if the resistor was soldered correctly. If not, and the solder joints need to touched up or the wrong value resistor was soldered to the board, the labor rework cost, especially in a high labor rate location, will add up rapidly. These defects have a much lower cost impact if the rework is done in a low labor rate operation.

As nature abhors a vacuum, human beings, in general, abhor change. In his groundbreaking book, *Who Moved My Cheese* [10], Spencer Johnson uses mice, allegorically, to present the different ways our species deal with change.

There is a sense of security in the status quo. Pushing away the risk that almost always accompanies change gives us that sense of security. Maybe this propensity for resisting change was designed into our DNA to keep us from taking unnecessary risks, increasing the probability of the species' survival. Who was the first person to suck a clam off the half shell or cozy up to a sleeping saber tooth tiger? Now that is what I call brave – or, would stupid be a better description. It comes down to risk vs. reward, cost vs. benefit.

In 1632, when Galileo presented the world with scientific proof that the planets and stars did not revolve around the earth as the traditional Ptolemaic system requires, he quickly learned how dangerous even the suggestion of change could be to his health.

Sometime the motivation for change, in both the way we think about things and how we manifest those thoughts into action, is presented to us when the condition or environment we find ourselves in changes.

ELECTRONIC ASSEMBLY LABOR RATE COST MODELS

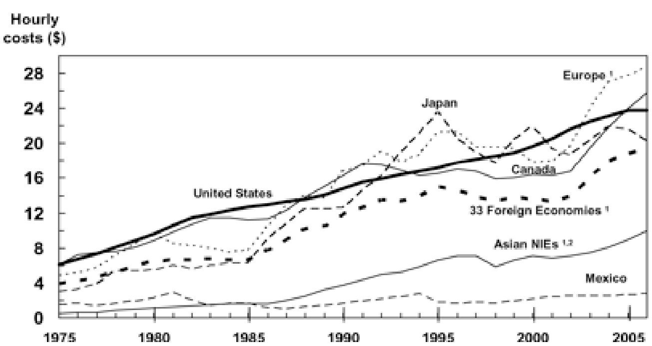
Let us first develop two generalized labor cost models that represent the existing low and high assembly labor environments. This will establish the gap between the models, define the elements that contribute to the gap, and provide visibility to which elements, if any, are controllable. For the purposes of this paper, we will analyze the respective costs of circuit board assemblies only – not box or higher-level assembly builds.

This analysis will address only the labor component of cost. In the models, raw material cost will be considered the same, regardless of the labor location – it is not. This disparity warrants a separate analysis, and is not addressed in this paper.

Generalized Cost Model

It is difficult to develop a series of models that everyone can agree with. At best, we are able blend industry and government data that are themselves averages of different regions, industry sectors and work that is done by the Original Equipment Manufacturers (OEM), i.e., The design source, as well as the manufacturer of the product, and the Electronic Manufacturing Service (EMS) provider, i.e., a contract assembler who builds products for OEMs. For example, the model for the automotive electronic assembly sector may be more heavily burdened with employee benefits if the assembly is being done by the OEM rather than at an EMS. Also, relative currency fluctuations can play a significant role in assembly cost.

In addition, in China, the cost of labor is strongly influenced by whether the assembly is being done in urban areas or by TVEs (town and village enterprises).



[1] Trade-weighed average
[2] The Asian NIEs are Hong Kong SAR, Republic of Korea, Singapore, and Taiwan

Figure 2. Global Hourly Manufacturing Labor Rate Trend Comparison [11]

Figure 2 illustrates how manufacturing labor cost has changed in a number of different countries and geographic regions over a 36-year history. These are employee compensation rates and include employee benefits. Table 1 adds the best available labor rate and trend data for China. Technically, the labor cost of a product does not include profit or fee. Adding the overhead costs that need to be absorbed, plus profit, to the raw material and labor of a product results in the selling price. For the purposes of this analysis, however, profit will be considered part of the overhead and loaded accordingly. Another way of saying this is that the models will result in the labor selling price.

Year	Basis (Yuan)	Basis (U.S. $)	Index (U.S. = 100)
2002	4.73	0.57	3
2003	5.17	0.62	3
2004	5.50	0.67	3

Table 1. China Manufacturing Hourly Rates, 2002-04 [12]

For comparison purposes, consider two companies, A and B. Company A is in a high labor rate area and company B is in a low labor rate economy. There are different ways to account for cost, e.g., activity based costing, labor-loaded costing. The point is that regardless of the system that is used, all the costs must be included. For this exercise, a labor loading system will be used. The same hypothetical circuit board is costed in both the high and low labor rate companies

High Labor Rate Model

Assumptions (in USD):

1. Wage (earnings): $20.17/hr
2. Benefits are 32% of raw labor: $6.46/hr
3. Employee Compensation (Earnings + Benefits) for U.S. manufacturing: $26.63/hr [13]
4. Overhead rate for full labor burdening is 250% of raw labor
5. Benefit cost is included in overhead rate
6. All indirect labor is included in overhead rate
7. Overhead rate includes SG&A (sales, general and administrative costs – generally, a percentage of labor and material)
8. Overhead rate 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 8 produce a labor selling rate of $50.43/hr
11. Fixed overhead (facility/equipment) is 4% of fully burdened labor
12. Variable (controllable) overhead is 56% of fully burdened labor and includes all indirect labor
13. Touchup labor costs $5.00/solder joint
14. In-Circuit Test (ICT) yield loss labor costs $25.00/ board to troubleshoot, rework and retest
15. Functional test yield loss labor costs $50.00/board to troubleshoot, rework and retest

Some of the other labor that is typically included in the indirect labor costs and needs to be absorbed into the labor selling price includes:

- Personnel to load bills of material into MRP
- A procurement department to get quotes and order material
- Industrial engineers who quote labor
- Master scheduler and planners who plan and release work orders to production
- Material handlers (in-shipping, material inspectors, pack and ship)
- Inventory and stock room personnel
- Production planners who release work orders
- Process engineers who develop assembly process and write methods sheets
- Kitting people who pull and kit material for released work orders
- People who deliver the kits to the appropriate equipment and work stations
- People who set up the stencil printers
- Set-up people who load material on component placement equipment
- In-process inspectors
- Technicians who troubleshoot the automated equipment process when it is producing defects
- People who perform maintenance on the production equipment
- Supervisors and managers for procurement, production, process engineering, test engineering, and quality assurance
- Human resources
- Factory safety officer
- Office and manufacturing cleaning personnel
- IT people to maintain and upgrade computer equipment

For each of these indirect employees described above, besides salaries and hourly wages, the following costs and benefits for each employee must be absorbed in the labor selling rate:

- Medical insurance
- Unemployment compensation tax
- Worker compensation insurance
- Social Security tax
- Medicare taxes
- Holiday pay
- Vacation pay
- Sick pay
- Pension or retirement plan contributions
- Training costs

Fixed overhead includes:

- Building costs
- Utilities: Power, natural gas, water, and sewer for the operation
- Computer and communication systems for the facility
- Spare parts for the operations and facilities
- Depreciation on the assembly equipment and facilities
- Insurance and property taxes on the assembly equipment and facilities
- Safety and environmental costs

Applying these high labor rate assumptions to a business model for a Tier 2 cost circuit board assembly operation (in USD):

- Sales/year = $1B
- The circuit boards have a 75% to 25% raw material-to-fully burdened labor ratio cost mix
- Of the 25% fully burdened labor cost, 50% is machine-based labor, 50% is hand-based labor

- Raw material cost/year = $750M
- Total burdened labor cost/year = $250M
- Total unburdened (raw) labor/year = $100M
- Total absorbed overhead/year = $150M

- Average board price $100
- Number of boards/year 10M

- Material $/board = $75
- Labor $/board = $10
- Overhead $/board = $15

- Fully burdened labor rate = $50.43/hr
- Raw direct labor rate = $20.17/hr
- Total absorbed overhead (includes material related labor and attrition costs, SG&A and profit) = $30.26/hr
- Labor hr/board = $10 per board/$20.17 hr = 0.4958 labor hr/board

Figure 3 illustrates the labor rate elements as percentages of the fully burdened labor sell rate.

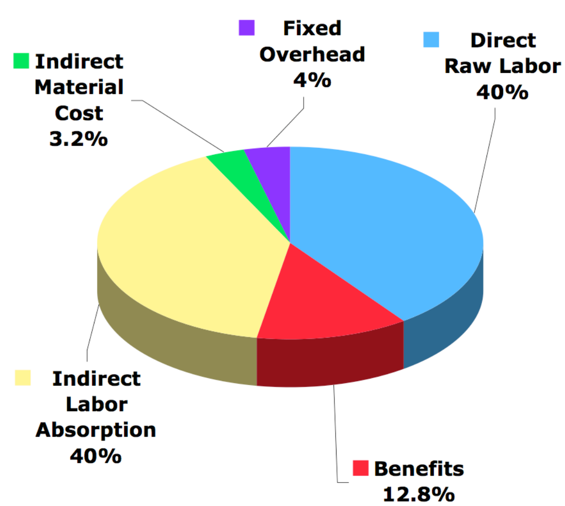


Figure 3. High Labor Rate Model ($50.43/hr) - Fully Burdened Labor Rate Element Percentages

Low Labor Rate Model
2004 Employee Compensation Rates for Manufacturing in China [14]:

Urban (City): 9.86 Yuan/hr = US $1.19/hr
TVE (Town & Village Enterprises): 3.73 Yuan/hr = US $0.45/hr
Average: 5.5 Yuan / hr = US $0.67/hr

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 fund

With the weakening of the dollar, the willingness of the Chinese government to begin to float their currency, and the continued upward labor cost pressure in urban centers, we will use an employee compensation rate of US $2.00/hr.

Assumptions: (in USD)

1. Employee Compensation (Earnings + Benefits) for China manufacturing: $1.19 [15]. As stated above, this analysis will use an employee compensation rate of $2.00.
2. Overhead rate of 300% will be used for full labor burdening and "reality" factor* considerations.
3. Overhead rate includes SG&A (sales, general and administrative costs – generally, a percentage of labor and material)
4. Overhead rate includes material handling, inspection and attrition (usually loaded as a percentage of the raw material cost)
5. Profit or fee is included in overhead rate to result in a fully burdened labor sell price
6. Assumptions 1 through 5 produce a labor sell rate of US $6.00 / hr.
7. Average touchup labor costs $0.10 per solder joint

*Anecdotal data suggest the actual fully burdened labor selling rate is between $5 and $10/hr [16]

These assumptions are now applied to the same general business model used for the high labor rate circuit board assembly operation:

- Sales / year = $1B
- Total raw material/year = $894M
- Total burdened labor cost/yr=$106M

- Labor hour usage per board is 3 times greater than in the high labor rate cost model = 3 x 0.4958 = 1.4874 hr / board
- Unburdened labor rate = $2.00/hr
- Fully burdened labor rate = $6.00 / hr
- Unburdened labor cost/bd = 1.4874 hr x $2.00/hr = $2.97/board
- Overhead absorbed/board = $5.95/board
- Fully burdened labor selling price/bd = 1.4874 hr x $6.00 = $8.92/board

- Average board price = $75 + 8.92 = $83.92 / board
- Number of boards/year = 11.9M

The fully burdened labor rate cost elements breakdown is illustrated in Figure 4. Note that since the individual contributors to overhead are not known or assumed as they were for the high labor cost model (Figure 3), the fully burdened labor sell price is simply the direct raw labor and the total overhead.

Labor Cost Modeling Results
The result of this modeling is that a $100 circuit board assembled and tested in a high labor rate environment sells for $83.92 if it is made in a low labor rate environment. To prove the *null hypothesis* it is necessary to show that the resulting $16.08/board price reduction cannot be overcome.

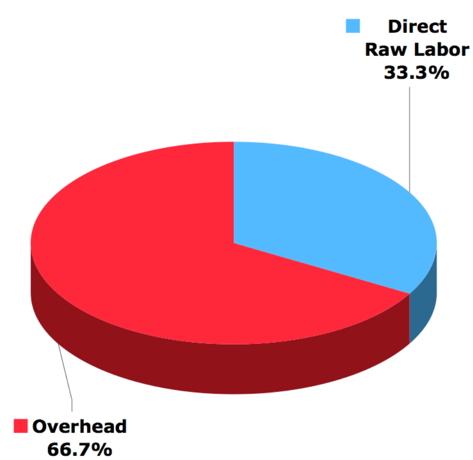


Figure 4. Low Labor Rate Model ($6.00/hr) - Fully Burdened Labor Rate Element Percentages

OBSERVATIONS ON THE EXISTING MODELS
Examining the cost elements of the two current models, the following observations are made:

1. The labor selling rate gap between the two models permits the low labor rate companies to *throw* a lot more labor at the assembly. In this low labor rate model, higher skilled (and cost) labor that can develop capable and controllable assembly processes may or may not be available. Whether they are or not, an alternate strategy is to merely

address in-process quality issues with labor-intensive, post-automation rework touch labor.
2. When faced with low yields in a high labor rate environment, the high cost of troubleshooting, reworking and retesting assembly defects (and scrapping material) can be a significant factor in the inability to compete. The low labor rate competition may simply mask this root cause of the failure to compete.
3. Of the elements that contribute to the labor cost in the high labor cost model, the largest controllable elements are: direct raw labor cost and indirect labor absorption cost (Figure 3)
4. Soft considerations such as the logistics challenges of assembling products in remote locations, the cost of doing business (increased travel costs and time), measuring and analyzing performance in real time and the cost of changes to products are difficult to quantify, but are real.

AN ALTERNATE HIGH LABOR RATE COST MODEL

Can we develop an alternate high labor rate model that closes the cost gap between the current high and low labor cost models (about a 36% labor cost difference for our hypothetical board)? The industry today answers emphatically: No! But, before judging the *null hypothesis* as proven, an attempt to drill down into the two primary cost differentiators is in order: the difference in the raw labor and the difference in overhead rates.

Those who have been working in a high labor cost electronic product assembly environment have been largely working at cross-purposes. On one hand, they have embraced an assembly technology that continues to get more and more complex. This complexity is a function of three factors that have emerged primarily as a result of the evolution in electronic component design and packaging (Figure 1). These are:

1. Advances in robotics and other forms of machine automation.
2. An increased complexity in the assembly process.
3. The need to better understand and incorporate more physics (when we were exclusively hand-soldering, the terms *thixotropic*, *rheology* and even *hydroscopic* were terms rarely heard around the workbench).

Ironically, this added complexity has been addressed by a relentless management quest to find less expensive, low skilled labor to deal with the low labor rate competition! Some of that inexpensive labor is needed to accommodate a circuit board design that can't be fully automated. But, unfortunately, even for the part of the design that can be automated, the advanced skill sets required to create capable and controllable assembly processes are either not available, or management is unwilling to pay for them. The result in many cases is increased cost for touch-up, rework and material scrap. "Keep looking for that low cost direct labor. We have no choice! Build! Build! Build! Rework! Rework! Rework! Ship! Ship Ship! Ah, we met our monthly sales goals" (maybe by wrapping a $5 bill around each board that was shipped)! In this case, the goal should be to ship LESS next month since, the more boards shipped, the more money is lost. A company in this mode of operation becomes trapped in a death spiral. They will either go under, be sold or go offshore. Do you think the consolidation that we have seen over the last 10 years - companies gobbling up other companies – is a result of good fiscal performance? In most cases, it's a quick way to affect the bottom line. Add someone else's puny net profit to our puny net profit and survive another year.

Increase profit by reducing cost? How about having the direct labor pay the company to work here? Both have about the same chance with the existing management team hard at work steering this ship. The way they see it: "It's that cheap labor we have to compete against. Let's move offshore or get sold." What if we take a deep breath, take a step back and consider a new three-step strategy.

1. *Transformation of the direct labor workforce.*

U.S. industry has a history of assembling products in geographic areas whose labor costs can successfully meet competitive pressures. It is interesting to note that in most cases this happens only when a particular industry is threatened by the competition's lower prices. For example, shoemaking and textile industries thrived in New England in the 19th and early 20th centuries. Prices rose. Organized labor put further pressure on cost. Manufacturing continued. Southern U.S. companies and foreign factories began to produce products for lower costs because of the availability of cheap hourly labor. Automation reduced labor content, volume production increased and costs decreased, but the industries were still basically labor intensive. It was then that textile and shoe manufacturing left New England and moved to the South – then, they moved to the Deep South, then the Caribbean, then Mexico, then South America, then the Pacific Rim, now China.

Cars and electronics followed. Again, improvements in automation slowed the transition, but still the drumbeat continued, *reacting* to the low labor rates that the competition acquired access to – not *anticipating* them. "It's time to move manufacturing again." This process was, and continues to be, repeated over and over even though the capability and quality of the automation in some industries provides the opportunity to reduce the theoretical labor content to a very small percentage of the total product cost. When this happens, the labor rate plays a relatively small competitive role. This is certainly true of most electronic circuit boards – but we don't exploit the automation fully. Why? The answer is: it's harder than looking for cheap sources of labor, we don't have the time, we don't have skills and we certainly don't have the vision and courage. No one ever says this, of course.

Notice also that the companies that are most successful in high labor cost regions seem to be small operations with flat organizations (*lean*, we like to say these days). This creates the perception that high labor cost operations are good at competing on low volume and prototype work, but the industry experts maintain, "Sorry, with those labor rates we need to go offshore for the high volume stuff."

The Low Volume / High Volume Paradox

In *Paper or Plastic? Choosing to Move Offshore* [17] a challenge is made to the logic of those who have relegated all future high volume manufacturing to low labor rate geographic regions. "…Finally, think about this – the 'experts' say, 'Future volume manufacturing will all be done 'over there' - we just can't compete in high volume manufacturing.' Oh, really? I thought high volume manufacturing requires LESS labor per assembly, not more, since NRE, fixture cost, set-up time etc. is spread over a large number. Since we pay more for domestic labor (for example, in a high labor rate region like the U.S.), we should be able to compete more effectively when building products domestically with less labor dollars per assembly. If we automate and just let the line run, doesn't the offshore *low cost* labor advantage asymptotically go to zero?"

The unspoken little secret is that for high labor rate cost environments, the higher the volume, the greater the impact poor yields have on their ability to compete. The answer to the paradox is that the higher the volume, the more defects there are that need touch up and rework – and it costs high labor rate operations a lot more for rework because of its labor intensity.

Figure 5 illustrates the two basic paths to reduce raw (unloaded) labor costs:

1. Reduce the hourly labor rate applied to the unit labor hours.
2. Reduce the unit labor hour content.

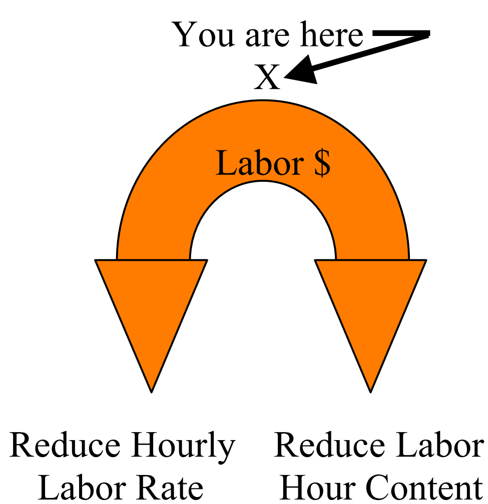


Figure 5. Two Paths to Reduce Labor Cost

Traditionally, we have tried to compete (reduce labor cost), primarily by taking the left path.

The new model replaces the large, low rate labor force with a small, high rate group of mostly engineers who are multi-skilled and self-managed. This results in a higher average labor rate ($26.63/hr to $38.34/hr), but reduces overall labor cost by reducing labor content, including the elimination of in-circuit test as part of the assembly process.

Do We Sell In-Circuit Test or Products?

In-circuit test (ICT) adds no value to the customer. The customer wants a product or circuit board that does what the product or board performance spec. says it should do. This is usually determined by a functional test. Why, then, do we do ICT? Unfortunately, it is usually used as a way to separate the good boards from the bad boards we build. In order words, we use ICT as a coping strategy to deal with an assembly process that is not capable or in control, or both.

If ICT yield rates above 99% can be achieved, the cost to do the test does not pay back; i.e., finding one defective board for every 100 that are built. Without the need to do ICT, the need to do post ICT troubleshooting, rework and retest is eliminated.

2. *A corporate model that focuses on the assembly of the customers' products and not on technical disciplines or departments within the organization.*

We have evolved into an industry of indirect labor specialists. We have a corporate structure that puts each of us into our own silo. Our particular silo (department) tells us what specific role we will play in the company's operation.

This is consistent with the division of labor and assembly line product flow of the early electronic assembly factory floor. Operator Number One inserted components R6, C12, U4, U16, and Operator Number Two inserts R1, R5, C6, U2 and so on, as downstream operators continued the process until the board was complete. In a similar way, a marketing person generates a product specification. From the specification, the electrical engineer designs the circuit, creating a schematic, and passes it on to the CAD person who lays out the board. The CAD person passes the design package to an industrial engineer who methodizes the design for production. The bill of material goes to someone in the procurement department to order the bare board ad components. The design package goes to the electrical test department to have in-circuit and functional test developed, etc. Each department is like an island or a community with their own identity – success being measured by how well they do their specific job. The customers do not buy specific jobs – they buy products.

This fiefdom-like organizational structure promotes department focus and competition, many times at the expense of the customers' products. As important, this structure is very expensive with much of the indirect labor adding questionable value.

Instead of trying to just cope with these issues as we have a history of doing, the new model dismantles the traditional hierarchical structure. Just two groups replace all departments. The new multi-skilled, engineering-based direct labor is organized into self-managed customer product teams. A small leadership group serves as an enabling function, providing the product teams with the skill sets and tools they need for success. This permits a dramatic reduction (40%) in overhead cost because of a combination of the dramatic reduction of indirect labor, and the aforementioned dramatic increase in yield.

3. *Creating an educational environment that serves the needs of the new model.*
The type of fundamental change described above does not come easily. It is a daunting task to reduce labor cost sufficiently to compete with labor rates in the order of $1.00 per hour by taking the right path in Figure 6 (reducing labor hour content). A prerequisite is having a labor force that meets the demands of the new model. The current academic community is incapable of providing this workforce. Educating in one community (academia) and sending the educated to work in another community (the real world) has created an ever-increasing gap between academic preparation and industry need. High tech electronic product assembly simply changes too quickly to have its needs provided in an environment where it can take 2 – 3 years to get a curriculum changed. We need to create a *teaching hospital* of sorts for the high tech electronic assembly industry. A learning community should be established that wraps a school around a for-profit contract manufacturing facility, where students can be taught in a real-world environment for the full tenure of their post-secondary education [18].

The High Labor Rate Cost Model Revisited
Assumptions (in USD):

1. Raw labor wage (Project Engineer): $29.05/hr
2. Benefits are 32% of raw labor: $9.29/hr
3. Employee Compensation (Earnings + Benefits) for U.S. Project Engineer: $38.34/hr [19]
4. Overhead rate for full labor burdening is 150% of raw labor
5. All indirect labor is included in overhead rate
6. Overhead rate includes SG&A (sales, general and administrative costs – generally, a percentage of labor and material)
7. Overhead rate includes material handling, inspection and attrition (usually loaded as a percentage of the raw material cost)
8. Profit or fee is included in overhead rate to result in a fully burdened labor selling price
9. Assumptions 3 through 8 produce a labor selling rate of $57.51/hr
10. Fixed overhead (facility/equipment) is 4% of fully burdened labor
11. Variable (controllable) overhead is 26.1% of fully burdened labor and includes all indirect labor
12. Touchup labor costs $5.00 per solder joint
13. In-Circuit Test (ICT) yield loss labor costs $25.00 per board to troubleshoot, rework and retest
14. Functional Test yield loss labor costs $75.00 per board to troubleshoot, rework and retest

Applying these assumptions to the same Tier 2 high labor cost circuit board assembly operation business model (in USD):

- Sales/year = $1B

- The circuit boards have a 75% reduction in direct labor hours from the original high labor model because of:
  1. Full exploitation of automation (boards designed for automation)
  2. The near elimination of touchup and rework: Assembly yields of 99.5% - only 1 board in 200 requires touchup or rework – capable processes are developed and kept in control by proactively monitoring process parameters in real time
  3. Because of high yields, In-Circuit Test is eliminated

- Overhead rate is reduced 40% by organizational restructuring
- Fully burdened labor rate = $57.51/hr
- Raw direct labor rate = $38.34/hr
- Total Absorbed Overhead (includes material related labor and attrition costs, SG&A and profit) = $19.17/hr
- Average Labor hr/board = 0.1240 labor hr/board

- Material $/board = $75
- Labor $/board = $4.75
- Overhead $/board = $2.38

- Average board price = $75 + $4.75 + 2.38 = $82.13

Figure 6 illustrates the labor rate elements as percentages of the fully burdened labor sell rate.

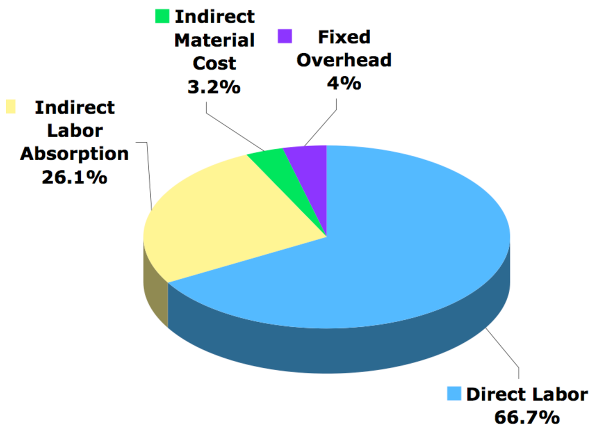


Figure 6. Revised High Labor Rate Model ($57.51/hr) - Fully Burdened Labor Rate Element Percentages

Model	Material Cost	Direct Labor Cost	Absorbed Overhead Cost	Circuit Board Price
High Labor	75.00	10.00	15.00	100.00
Low Labor	75.00	2.97	5.95	83.92
Revised High Labor	75.00	4.75	2.38	82.13

Table 2. Model Comparison (Costs/Price in USD)

CONCLUSIONS

Thomas Jefferson knew the wolf's ears could not be held forever. Changing the way we think about electronic assembly in high labor rate environments is a big ship to turn, filled with trepidation and risk. This paper demonstrates the *null hypothesis*: *it is not possible to competitively assemble electronic products in high labor rate regions of the world* is not true (Table 2).

However, even if the *null hypothesis* is true at this time, i.e., perhaps you don't accept the model assumptions, low cost labor markets will not be labor intensive forever. Available automation and, more importantly, the ability to develop capable automated processes that are kept proactively in control, will be embraced. These changes will be accompanied by upward pressure on labor rates in these regions as middle classes develop.

But, why would those in high labor rate regions squander the edge they currently have? The ability to reduce labor content by exploiting the available automation, accompanied by a dramatic reduction in overhead costs that breaking free of the traditional manufacturing corporate model affords, will permit successful competition with low labor rate markets – now.

Is it time to let go of the wolf's ears? I think it is.

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