



Research Paper

OPTIMIZATION OF A FLEXIBLE MANUFACTURING SYSTEM (FMS) FOR HIGH TECHNOLOGY PRODUCT PRODUCING FACTORY VIA THE MODULARIZATION OF PRODUCTION SYSTEMS

Prashobh Karunakaran^{1*} and Mohammad Shahril Osman¹

*Corresponding Author: **Prashobh Karunakaran**, ✉ prashobh.karunakaran@gmail.com

This research is timely because many High Technology Product Producing Factories (HTPPF) are still following the trend of factories that produces the likes of canned food or even cars where all machines are jointed from start to end (Towill, 2010). These HTPPF have not realized that improvements to product must be done everyday to keep market share. And to perform research continuously, buffers in-between production machines is a necessity. The absence of this has caused a number of hard disk manufacturers to close down, especially in Japan and Taiwan (notably Sony, NEC, Matsushita and Trace), which are leaders in joining up production lines from start to end. It is due to this that currently 90% of hard disks are produced by Western Digital and Seagate, with Toshiba having 10% market share.

Keywords: Buffer, Modularity, High Technology Product Producing Factory (HTPPF)

INTRODUCTION

HTPPF can best be run with buffers in-between production machines to enable research initiatives. The main reason why researchers prefer to perform hypothesis test on the production line rather than on a dedicated research line is the accepted fact in the production of hard disks, for example,

upon start-up of a line there is a yield drop and this yield picks up after a while. Therefore on a research line that is not always running, it takes from an hour to a few hours before the yield stabilizes. This discourages researchers from performing tests on the research line. In a production line where the yield is already at around 98%, a small change in say a chemical

¹ Faculty of Engineering, University Malaysia Sarawak (UNIMAS), Kota Samarahan 94300, Sarawak, Malaysia.

in one particular machine in the line can more easily be examined. Also by using production lines as test beds many lines can be used, so sampling of research can more easily be done. Thus there is a consistent data base to validate results. Research lines are still available for major changes especially where mechanical changes to machines are involved, but for quick validation of results, the running production line is used (Ting, 2012). While developing new strategies for increasing research in HTPPF, other major problems were encountered, one being the bottleneck caused by the Defect Detection System (DDS) and the other being the wastage in the current system of customer ordering products, factories manufacturing them and how it is finally delivered to customers. This researcher had fourteen years of working experience in the Western Digital hard disk factory in Kuching, Malaysia, where research is done everyday to improve the Key Quality Characteristics (KQC) of hard disks.

LITREATURE REVIEW

The review of various types of flexible manufacturing was done including how the current factory setup was originally devised. Manufacturing started with Custom Manufacturing. In Custom Manufacturing, a carpenter made furniture, a cobbler made shoes and a tailor made clothes. These people had all the skills required to make the entire product. Today, special projects like the ASIMO robot, spacecraft, special furniture and special clothing are still custom manufactured. As demand grew these skilled craftsmen could not meet the increasing demand of the people so Intermittent Manufacturing was developed. This is a set of small factories where products

were made in batches like a batch of ten brooms at a time. The parts for a product are made at a time. Say ten wooden rods are turned from the raw wood. Then ten bottoms of the brooms are cut to shape from the raw wood. Then the ten bottom of broom are drilled with holes. Then the holes of the ten bottom of broom are stuffed with the plastic brushes to make the final broom. Continuous manufacturing was first developed in the Ford Motor company. There was a continuous demand for the Ford Model T cars so a conveyor system was developed where workers added parts to the cars at each station.

This was the beginning of the human drudgery of performing repetitive tasks like machines in factories. Instead of manufacturing say only ten brooms at a time, a continuous output of brooms are manufactured. At each workstation a particular task is performed to make the broom. Workers at each station are trained to accomplish their task as quickly as possible. Today most consumable products are manufactured in this way except that human are often replaced by robots (Kalpakjian and Steven, 2005). The next manufacturing system is called Flexible Manufacturing System (FMS) where computer and communication technology is increasingly utilized. In a FMS, products are manufactured in lots but the process is continuous and highly automated and generally controlled by a central computer. FMS is a group of computer-controlled independent machines linked by material handling systems that are able to produce a wide variety in types and quantities of products. All the machines are controlled by a central computer running a Human Machine

Interface (HMI) software which normally includes a SCADA system. Often there are no humans even at the HMI computer. Many HTPPF management mistakenly believe that is the ultimate trend and work toward automating everything without buffers, thus hampering research initiatives.

Since factories are increasingly being automated, details of the latest available robots and capabilities were also studied. The available configurations of robot arms are SCARA (four axes robots – Selection Compliance Assembly Robot Arm), Vertical multi-joint (six axes robot or articulated), Cartesian coordinates (two axes also known as Linear Module), Cylindrical coordinates (two linear axes plus one rotating axes) and the last being Spherical coordinates (one linear axis plus two rotary axes). The Adept Cobra i600 is a SCARA robot. It is the first Adept robot with the amplifier unit built into the robot arm (beyond a heat sink at the back of the robot). Robots can change End-Effectors which are like changing fingers according to the type or shape of the product it will pick up. The Teach Pendant is a critical portion of the robot. The Teach Pendant is used to move the end-effector to the product being processed and then this location is stored as a variable (like X) with the instruction: “here X”. Later to move to this particular location, the instruction used is: “move X”. The teaching of the location of the product must be extremely accurate because sometimes the robot arm have to move to this particular point to pick up the product for 24 h a day and for many months after the initial teaching.

Major developments in factory machinery especially to prepare for future product

generations are slow due to the huge capital invested in existing HTPPF machines and the large amount of capital such industries generate. The view that a process that is still generating big income requires no update is what kills big companies. The scale at which such industries can be is depicted by the mostly Shenzhen based Foxconn which utilizes about a million workers to create revenue of \$94 bn in 2011 (Foxconn Reports Record High December Revenues). With such big money and number of employees, the resistance to major changes to cater for future generation of products is much greater. A general view is that big companies with highly educated people cannot make major mistakes. A classic example to counter this is IBM. IBM invented the hard disk and was the main hard disk manufacturer in 1994 when it started to change the hard disk media from Al-NiP to glass. IBM was so confident that this is the direction to take that they shut down all their Al-NiP plants while the rest of the hard disk industry stuck with Al-NiP. The reason why glass was thought to be superior was that it was better able to handle head crashes onto the disk while a head crash onto the Al-NiP will cause a ripple just like throwing a stone into a calm lake, therefore destroying lots of data (Zhang *et al.*, 2011). The problems is, there is a huge data base on metallurgy developed since mankind started making swords, while glass is a relatively new material, therefore while Al-NiP factories were able to increase data capacity, IBM struggled. The Al-NiP factories also later developed systems that prevented the heads from ever contacting the disk via various sensors placed within the hard disk to detect external movements. Another major issue was that glass can not dissipate heat from disk as it

spins below the head, while the AL-NiP disk can dissipate it via the hub which holds the disk; heat destroys magnetic data storage. Eventually this inventor of hard disk had to sell off the entire division (Christensen, 2010).

METHODOLOGY AND RESULTS

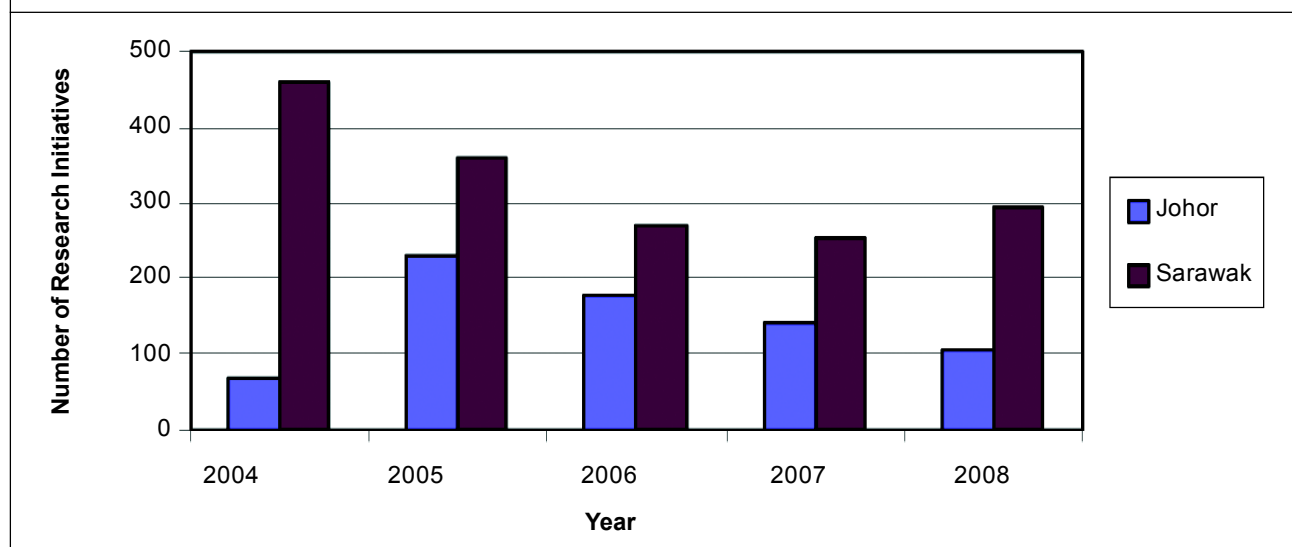
Data was collected of the rate of research activities for the Western Digital (WD) factory in Johor, which is fully automated without buffers, versus the WD factory in Sarawak which has humans operating the buffers in-between automated production machines. In the current hard disk industry, companies are still bent on full automation (without buffers) neglecting the data depicted by the chart in Figure 1; the exception being WD and Seagate which in recent years are following the Sarawak factory model, with human buffers in-between machines, because automated buffer systems has not yet been designed. It is not that the Sarawak WD factory has superior research because

of the human filled buffers but because it has buffers stoppable by researchers. The aim of this work is to automate this buffer to enable researchers to easily perform their tests.

Empirical observations were also made at the Western Digital factory in Sarawak for the reasons why researchers in HTPPF prefer the actual production lines to test their hypotheses. These are:

- Faster turnover in research—a line of production machines need a whole team of technicians to operate and maintain. Researchers will find it hard to justify to the financially oriented top management for having this team because they could be idle for long periods in-between research activities. The research team technicians will have lack of work compared to the rest of the production staff and this could be frowned upon especially during performance reviews which will eventually lead to employees deserting the research teams.

Figure 1: A Comparison of Research Initiatives Generated by Two Factories, the Western Digital Factory in Sarawak and Johor, Malaysia



- The current process must be stabilized before introducing a change. An empirically observed situation is that unfailingly, a newly started production machine will always have more defects, especially mechanical defects and particles than a line which has been running for a few hours. Engineers in factories are still baffled by this empirical observation which goes against logic because machines which just went through preventive maintenance (PM) have new parts and a thorough cleaning of the machine is always done after PM. The most probable cause is not the mechanical parts but the fact that the stirred up chemicals, filters, and other Operation Supplies Required Materials (OSRM) in a machine that has been running for some time is more conducive for the process than chemicals that have been stagnant for a day or more. One of Western Digital's (formerly Komag) factory in Japan, concluded that even if the inner circumference of the pipes are clogged with coagulated chemicals, the process is still stable unless these pipes are disturbed by the PM which dislodges particles from the clogged up chemicals. The PM for the pipes involves pumping either hydrogen peroxide (H_2O_2) or nitric acid (HNO_3) (depending on if the process chemical is acidic or alkaline respectively) in the pipes for a duration of one to six hours (minor or major PM respectively). It is for this reason that PM on the pipes was not done for this Japanese factory and instead all the pipes are changed after a certain span of time.
- In HTPPFs, most production materials and OSRM like filters, chemicals and liquid

abrasives require constant stirring to prevent settlement or coagulation. This is usually harder and expensive to maintain in a seldom running line, like a research line. So starting up a research production line to test out a small change in the production process requires a day of wasted production before the process stabilizes.

- More samples of the test can be carried out. A researcher can test out an idea on say five production machines and take another five lines as controls. With more samples the conclusion can be more accurate. The overall change in the KQC of the resulting product due to the incremental research change on the product is often very small and deciphering a conclusion may prove difficult. So the more samples and controls there are, the easier the research objectives are achieved.

Considering all these potential problems of running a newly started production line, researchers tend to prefer performing their test on production lines which are continuously running everyday for 24 h. Thus in conclusion, buffers between production machines in HTPPF are a necessity because it is easier to get management approval for research initiatives, it enables maintenance to be carried out more easily, throughput improvements of a particular machine within a long line is enabled and multiple product are more easily produced.

Four research problems were worked upon, the first being a system of automated buffers to replace the current manually operated buffers. Buffers are necessary in HTPPFs to

facilitate researchers in testing out their hypotheses. In a long production line without buffers, stopping machines has two problems. Firstly approvals will be needed from various levels of management because of the impact to production in stopping a big connected line of machines. Secondly products will be damaged as they are left idling in chemical filled lines for long periods of time. Currently buffers in HTPPF are manually operated. In the hard disk industry, cassettes of disks are manually placed onto carts; where human made damage to product is rampant (even whole cassettes have fallen off the cart especially during night shifts), and there is no traceability of the product. Traceability is important in HTPPF because in case a defect was detected at the final Defect Detection System (DDS), the disks with defects must be segregated and removed from production. It is because of these factors that the buffer should be automated.

The first design was an automation of the buffer in-between HTPPF machines (Figures 2 and 3). Specifically the disks are placed in RFID coded cassettes and stacked on three layered tunable shelves. The reason for three layers is the standard dimension of floor to roof in a hard disk factory and the size of an off-the-shelf, six-axis factory robot. For this buffer to have more layers the robot arm must be custom built. The robot moves up and down with the help of a ball screw. Moving robots up and down on a ball screw system has never been done before (Binding, 2010) because factory robots have facilities going up to it. Currently most factory robots have a CPU and an amplifier to amplify the signals coming out of it before it goes into the robot arm. But it is

Figure 2: The Design of the Buffer System in-Between Machines (Solid Works Software Sketch) Which will Facilitate Research Initiatives in HTPPF

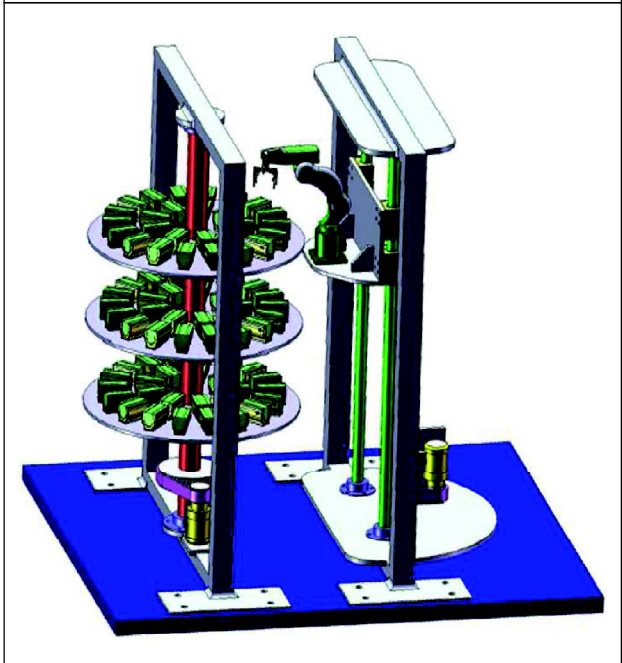
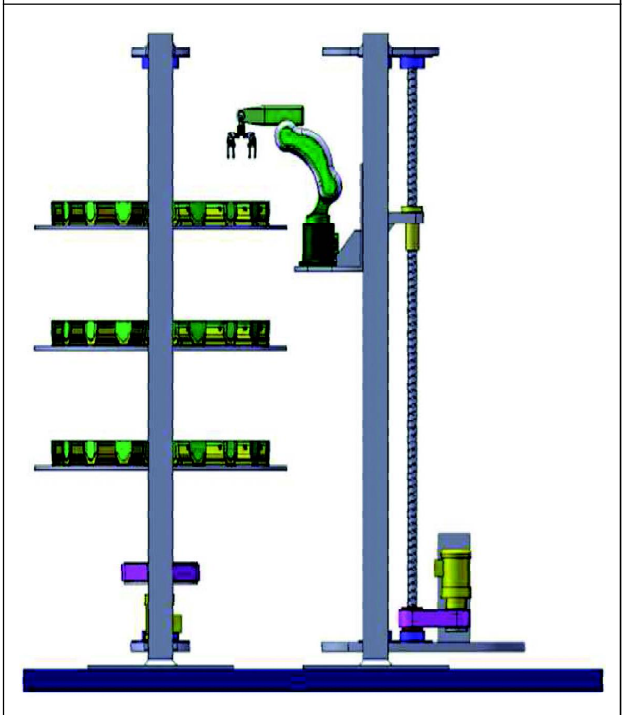


Figure 3: Side View of the Automated Buffer

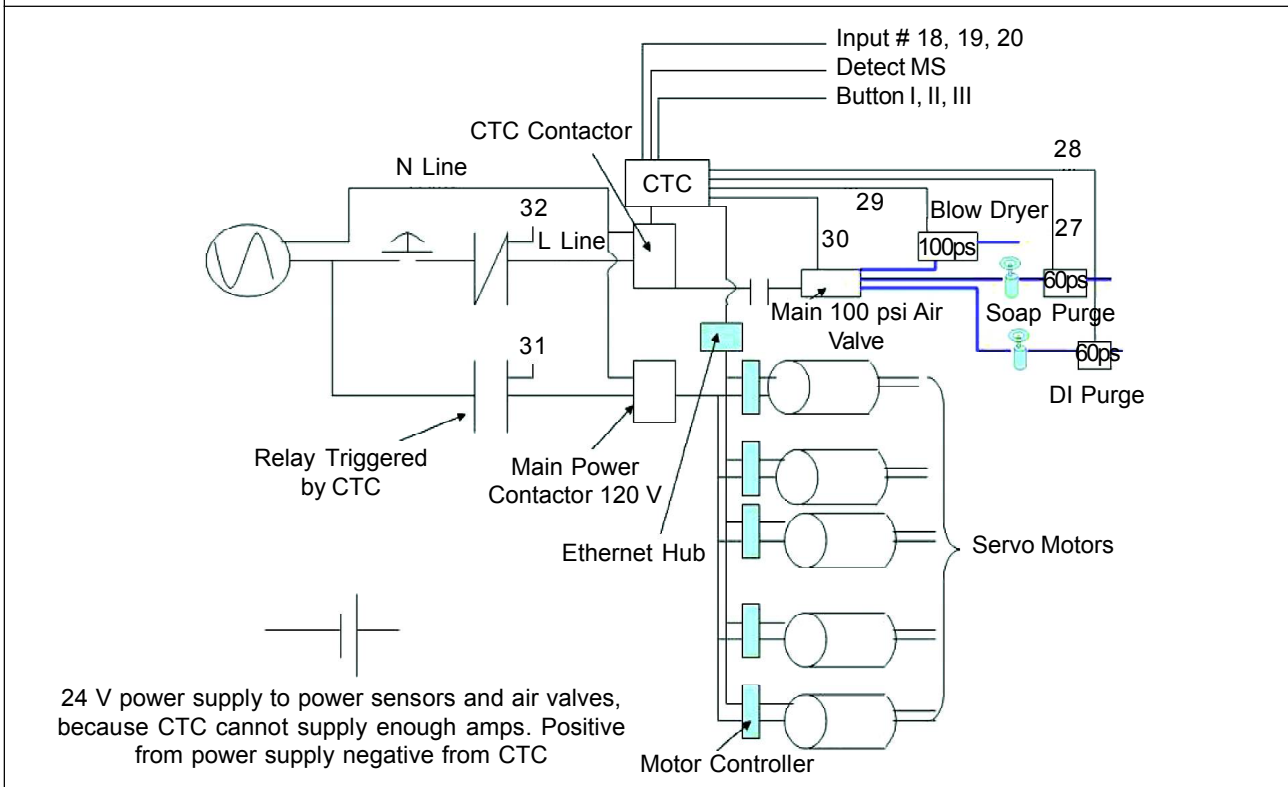


possible to build-in both the CPU and the amplifier into the robot arm (Kalpakjian, 2005). The facilities required are power wires, signal wires and pneumatic pipes. Wireless power is a recent advance developed at MIT (Massachusetts Institute of Technology) (Gozalvez, 2007). Basically a normal 50 Hz power transformer already has wireless power transfer between two coils separated by a paper. If the frequency is increased to the megahertz range the separation of coils can be up to many meters. Wireless signals has long been around as in cell phones but has not been implemented for factory robots, mainly due to concerns of hackers penetrating the factory robots. Therefore to communicate signals wirelessly to factory robots, security software must be sourced for what is already

available or specifically developed. For the pneumatic system within the robot arm, Clean Dry Air (CDA) supply can be sent to the robot arm by installing a small pump with a filter at the robot arm itself.

Once the automated buffer has been designed, there is a need to design a better way to stop the production machines. Researchers need to be able to stop production machines upon getting an inspiring idea without causing damage to products. Currently when a researcher stops the production line it is quite messy, with products being placed in temporary storage containers (if wet) or in cassettes on carts while the researcher makes the changes. This current system requires lots of human handling and therefore damage to the products. So a novel

Figure 4: Basic DPCL Wiring Schematic to Enable Machine Stop (MS). The Bigger Bold Letters Represent Changes



machine stopping method was designed specifically to cater to the needs of researchers within HTPPF. Figure 4 shows the modifications needed in one factory machine to cater to MS. The designed improved stopping device called Machine Stop (MS) has three modes of stopping. If Button i pressed, the machine will stop with memory, i.e., stopping just like an EMO (Emergency Machine Off) does, but machine has memory of last positions before stopping. This is enabled with the help of the recently available encoders with battery backup. Thus the robot will not need to do a “homing” upon startup. If Button ii pressed, the stopping will occur after finishing the current process. Say a machine has nine processes and the researcher may want to stop it after the second process to test an idea, so the button ii must be pressed during the second process. If Button iii is pressed, all the existing products from the machine will be cleared before stopping.

With an automated buffer and a proper way to stop machines designed, the bottleneck of the production line needs to be resolved. The bottleneck is always the product Defect Detection System (DDS). So a novel DDS was designed to cater to hard disk manufacturing. In the current system, a laser beam is shot onto the hard disk and defects can be detected from the reflected beam. Instead of shooting a single beam of laser onto the hard disk, a thousand beams of different wavelength can be shot sequentially. Such an array of laser beams has already been developed by the fiber optic telecommunication industry to enable Dense Wavelength Division Multiplexing (DWDM). The reflected laser beam can be collected

using a fiber optic cable with the insulation stripped off. That is, the reflected beam is sent to the fiber optic cable cladding. There little literature on this because most researchers advance the sending of laser beams through the core and no one seem is advancing the laser beam movement via the cladding of fiber optic cables. Experiments were done to proof that this is possible. Data in Table 1 shows that as the angle of incidence of the laser beam to the fiber optic cable is as low as possible, the intensity of the beam at the core at the other end is greater. There are four reasons for

Table 1: Angle at Which the Laser Beam Strikes the Fiber Optic Cable versus the Percentagebrightness Observed at the End of the Fiber Optic Cable

Angle of Beam to the Fiber Optic Cable	Percentage Brightness at End of Fiber Optic Cable
3	98%
10	88%
20	78%
30	68%
40	58%
50	48%
60	38%
70	28%
80	18%
90	4%
100	5%
110	6%
120	7%
130	8%
140	9%
150	10%
160	20%
170	30%
177	35%

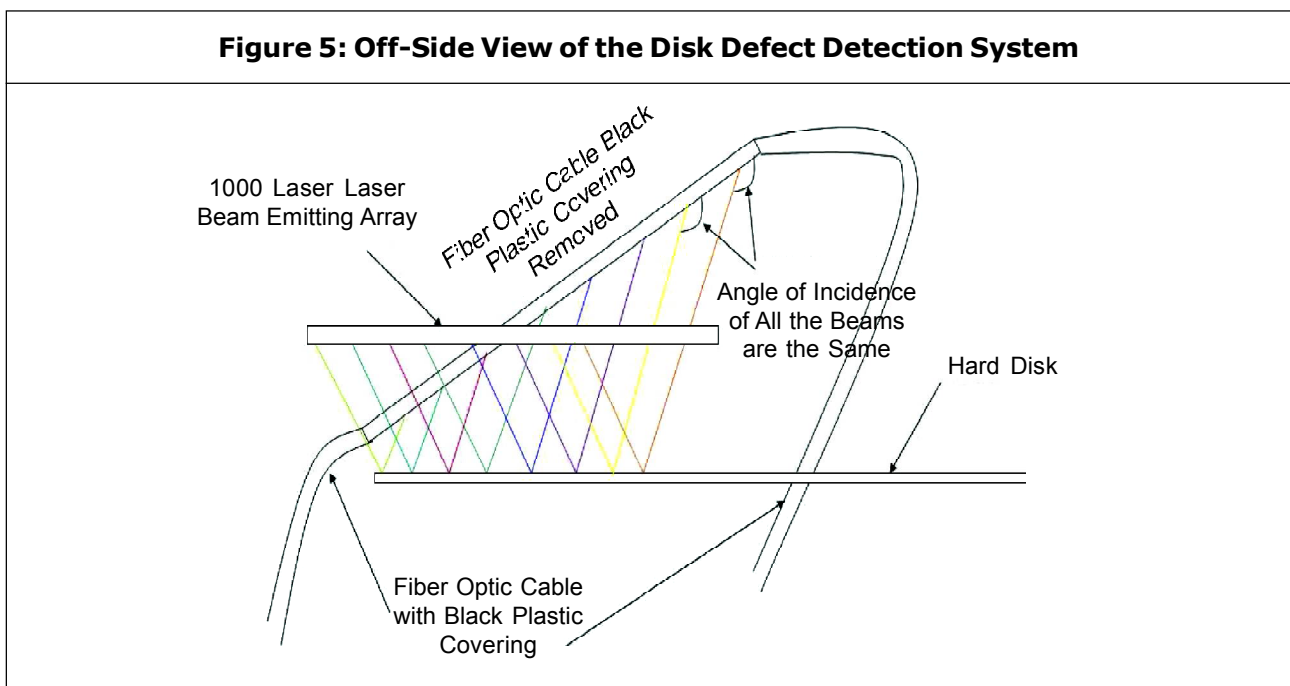
sending the reflected beam to a bare fiber optic cable instead of an array of 1,000 laser beam sensors:

1. The greatest advantage of using a bare fiber optic cable to capture the reflected beam is that when the laser beam hits a good portion of the hard disk, it will not be dispersed much but when it hits a defect, it will be dispersed greatly. Thereby the current method of using a single sensor (a small window) to predict what defect caused the beam to disperse is difficult. It is just like a human looking at a situation through a tiny window, they cannot see the whole picture. Using a bare fiber optic cable will increase the size of the window. Since the DDS design fires only one beam at a time, upon hitting a defect, this beam will be dispersed to a wide beam that hits the fiber optic cladding and later move into the core. Telecommunication technology already can study this beam sequentially; which is just like moving a camera over the defect

signature so a proper analysis of the defect can be made.

2. Because the source signal is a reflected laser beam from the hard disk, there will be scattering so this can trigger more than one sensor among the array of 1000 sensors.
3. It is difficult to align the array of 1000 laser sensors with the reflected beams in a factory environment compared to a telecommunication center where once it is aligned no humans will contact with it and it is placed in sealed temperature controlled environment..
4. Using an array of 1000 laser sensors is much more expensive than a bare fiber optic cable. Also changing out changing the fiber optic cable as it gets covered with dust is also cheaper.

This results in the corresponding design as shown in Figure 5 where the bare fiber optic cable was used to capture defect

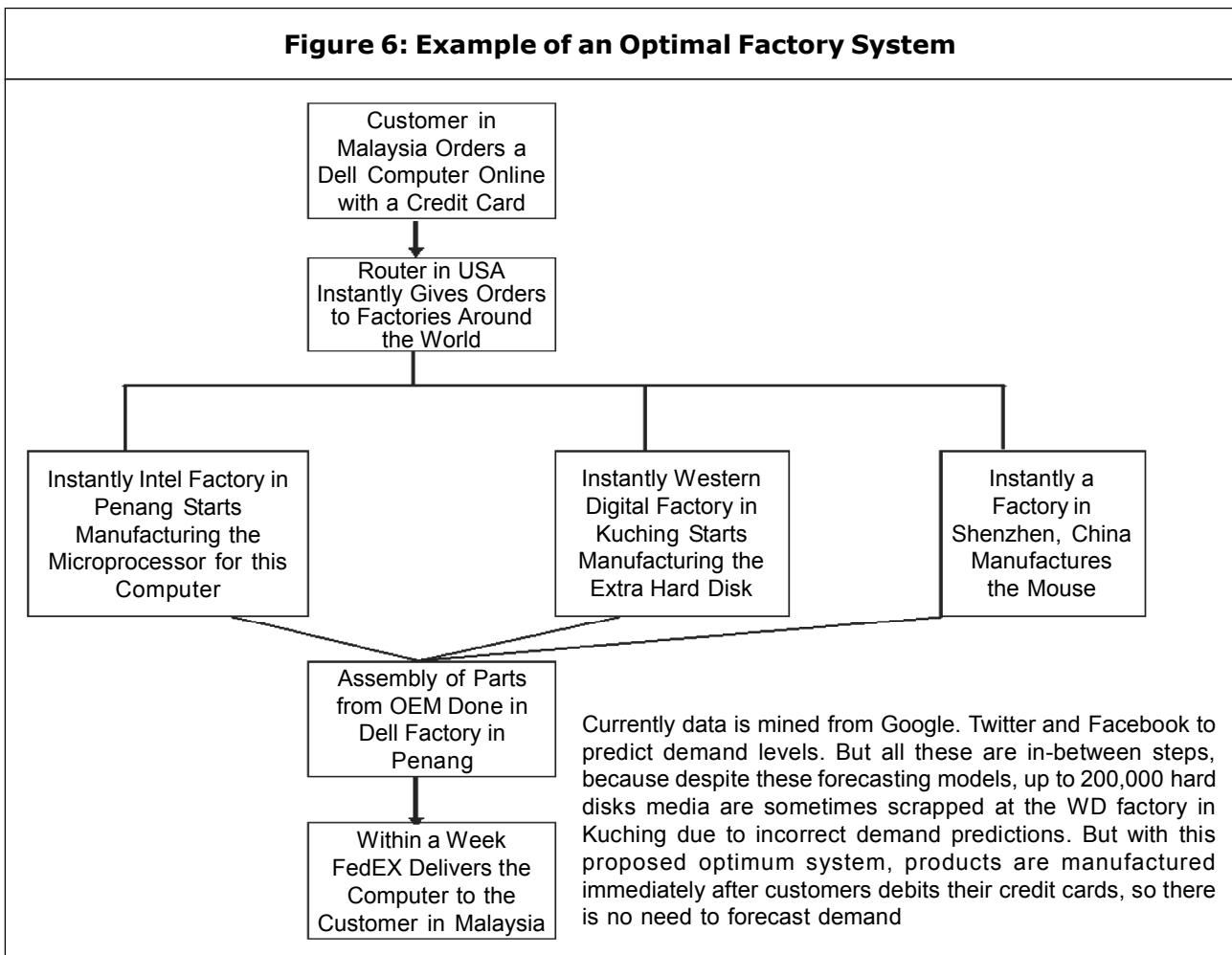


signatures from the laser beam reflected from the hard disk. This design was developed because placing a 1000 laser sensors to detect the reflected beam is much more expensive, is harder to align and also a single reflected beam will trigger more than one sensor. With this new system there will be no need for the tested disk to be turned for 4.5s below the laser beam at 12,000 RPM, one round could be enough, thereby increasing throughput by 900%.

With the automated buffer, a proper means to stop the production machines and throughput issues resolved, the next step is to design a method for customers in any country

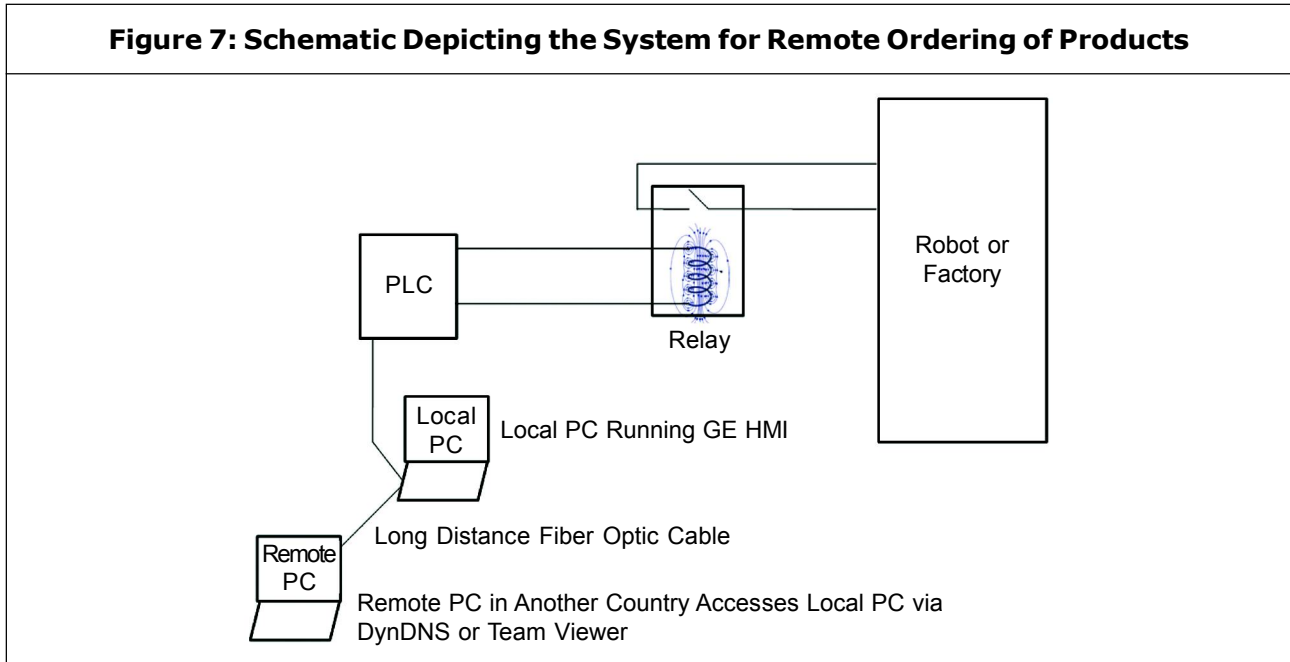
to order a product and this will be manufactured immediately by robots somewhere in the world. The justification for this is that the cost of manufacturing a product which has been paid for is much lower than the cost of producing it with predicted demand levels. Most factories mine data from the likes of Google, Facebook and Twitter (Bonneau *et al.*, 2009) to predict demand levels. But systems are currently available, whereby as soon as customers, somewhere in the world debits the money from their credit cards, humans and software process this order and gives instructions to other humans in factories to produce the product (Srinivasan, 2004; Garofalakis *et al.*, 2009; and Michael *et al.*,

Figure 6: Example of an Optimal Factory System



2010). An improvement to such a system is for customers in ordering a product with a credit card initiating factory robots to start manufacturing the product as depicted in

Figures 6 and 7. Security software must be developed or sourced from experienced anti-virus software developers, the likes of McAfee to couple with such a system.



JUSTIFICATION FOR AUTOMATION

There is also a need to justify advancing automation in factories as there are quarters that claim that such advances will take away jobs from the workforce. But paradigm shifts need to occur to view these automations as instruments that can liberate factory workers from the inhuman drudgery of pick and place jobs. Peering into human history will reveal that it was never natural for humans to be doing repetitive jobs for eight to twelve hours each day. Currently factory workers keep performing their jobs for the financial benefits they gain, knowing that the money is the shackle that keeps them almost as slaves to their jobs (Wen, 2007). This prevents them from having the normal human intuition to help improve their surroundings. Their tight work schedule

prevents them from developing skills that can enable them to earn a living in other ways. These jobs should be delegated to machines. At the Foxconn factory based in Shenzhen China, 14 suicides occurred in 2010, such that the factory actually installed nets to catch people falling down (A Look Inside the Foxconn Suicide Factory – Telegraph).

Industrialist and job seekers have to come to terms with the fact that, with today's international market place, customers from a rich or poor country will not purchase an inferior human-labor made part, while a superior quality and cheaper, robot-made part is next to it. People will only purchase the optimum product to suit their finances and needs and not to satisfy some patriotic ideal. Thus eventually competition will cause the human-labor intensive factories to shutdown. When

this happens, the only factory where a human can get employed will be at the automated factories which are producing high quality products at the lowest cost. Thus to increase employment, industrialists need to use automated machines and processes to find a niche in the international market. By slowly building up this niche with higher quality and precision, they will increase employment. Eventually HTPPF will be populated by researchers or other highly technical skilled workers (Zuehike, 2010).

CONCLUSION

The main hypothesis of this research is that buffers in-between production machines will enable HTPPF to innovate and thereby keep market share. The proof for this is the empirical observation that researchers in the WD factory in Sarawak prefer to use production lines to test their hypotheses. Also the chart Figure 1 indicates that the WD, Sarawak factory, which has manually operated buffers in-between machines, has a greater rate of research compared to the WD, Johor factory where all machines are jointed up. The other data is the empirical observation that HTPPF that do not have the understanding that buffers are important are losing market share or have closed down especially in Japan and Taiwan. These factories automate and join up all machines without buffers because it is the trend in all industries to do so. Top management reasons out that research lines is all that is needed to perform research, but as empirically observed, the research lines are frequently left unused in HTPPF unless there are major changes to the product. But majority of the changes are small and can best be performed

on the production line. While designing solutions to these problems, other problems were observed in HTPPF. First was a need for a higher throughput defect detection system for which a design was developed. The second was a justification and feasibility study on the ability for customers with credit cards initiating factory machines half across the world to manufacturing the product.

Future Work: Four future works can be suggested the first being a better statistical software coupled with sensors to enable factory engineers to more easily trace yield detractors within HTPPF. The second is a similar statistical software coupled with sensors to trace machine failure and therefore change out bearings and so forth only when they have gone out of specification. This will reduce down time of machines, increase yield and bring down overall production cost of the HTPPF. Work should also be done to bring down prices of ultrasonic sensors, which are installed outside pipes to detect flow rates within it. Current propeller and ball flow-rate sensors are becoming too inefficient and sources of contamination in HTPPF. As chemicals used in HTPPF gets purer to cater to the ever increasing capacity in smaller spaces, required in products (like hard disk), contamination from propeller flow meters becomes unbearable. Further more, while installing propellers flow sensors, pipes need to be cut which will contribute to the contamination. Fiber optic sensors can recently measure most physical properties and are non reactive to many chemicals, so research should be advanced in this field to bring down cost to affordable ranges. ◉

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