By Art Smalley

A Brief History of Set-Up Reduction

How the Work of Many People Improved Modern Manufacturing

Of the various topics I have studied over the years about the Toyota Production System none has been more confusing to me than the history of set-up reduction. Popular lore in the West and other parts of the world outside of Japan has Mr. Shigeo Shingo essentially inventing the concept during a breakthrough workshop in 1969 with Toyota Motor Corporation. His depiction of events in a book first published in 1983 details his insight that finalizes the formalization of the distinction between "internal" and "external" work and the need to shift more work to the external category. This step and several others he outlined are viewed as the keys to achieving single minute changeover performance. The account makes for a good story. In conversations with different parties and some brief research into the matter however there are about a half dozen other competing explanations for initial development of the topic. Some are quite earlier than 1969 and each one deserves to be understood in its own right.

Below I will outline a short list of the compelling arguments that I have uncovered over the years. I'll explain each one in order of history. I'll also state the case for each one to the extent I could verify the topic in some fashion. In the end I'm afraid that you'll see why it is a somewhat confusing topic and how the answer entirely depends upon what is your own personal definition of the words "set up reduction" and "invention".

1. G-Type Power Loom by Sakichi Toyoda
2. Cutting Tool Changes in Toyota's Machining Shops
3. Danly Corporation's Moving Bolster Press & QDC
4. Toyota Press Shops Internal Kaizen
5. Brazilian Forging Shop Influence
6. Shigeo Shingo and SMED
7. Nissan and Other Companies

G-Type Power Loom by Sakichi Toyoda

The G-Type power loom invented by Sakichi Toyoda is a tremendous machine in many respects. In no small measure this machine is partly responsible for the establishment of Toyota Motor Corporation and its production system. For starters the Toyoda family sold the rights to this loom in the early 1929 to the Platt Brothers & Co. Ltd in England for the eventual sum of about £87,000 pounds. This money was then budgeted for research and development work in a newly created automobile division in the family business headed up by Sakichi's son Kiichiro Toyoda. The early development work was a large struggle yet it was deemed successful enough to encourage the company to spin off the automobile division as a separate entity in 1937 which we now know as Toyota Motor Corporation.

Sakichi invented many different looms starting as early as 1896. The reason most TPS aficionados are familiar with the G-Type Loom from 1924 however is its famous "Jidoka" or automatic stop feature and other advantages as well. Several different types of automated looms already existed in the world at the time. They all shared a common weak point however. When a thread broke (i.e. a defect occurred) the machine kept producing and wasting yards of precious material until the operator or an inspector finally detected the problem. This required a person to stay in relatively close proximity to monitor the machine. Unlike other looms at the time the G-Type loom had a special mechanical feature that detected whenever a thread broke and stopped the machine automatically. An operator would then run over and reset the thread and work could then continue on. Due to this "build in quality" concept employees were freed up from monitoring one machine and experienced employees were able to handle a bank of 24 to 30 machines. An entire exhibit depicts this scene in Toyota's Commemorative Museum of Industry and Technology in Nagoya, Japan.

The Jidoka feature on the G-Type auto loom however is only one of no less then twenty four different patents that were filed on this revolutionary machine. One of the less publicized features however is the fact that it also contained the world's first *non-stop shuttle changeover device* as well. Until this machine's development operators would have to stop the loom periodically as the warp or horizontal thread would deplete the material in its spindle from time to time. This machine contained a new mechanism that automatically allowed a new spindle to be popped into place in advance with no loss of time at all. Operators could set up the next shuttle containing the spool of thread while the machine was still running. This in turn helped enable multi-process handling and increased productivity. It was this feature that reportedly most amazed the executives from the Platt Brothers & Co. Ltd of England and lead to the nickname "magic loom" for the device according to Kiichiro's biography by Kazuo Wada and Yui Tsunehiko entitled Courage and Creativity.

The G-type auto loom and its different functions are well understood by Toyota managers familiar with the history of the device. In many ways it approached the notion of a perfect machine at the time for its industry. First it was a low cost device compared to the competition in terms of both investment and operation. Second it was automated and thus greatly improved productivity. Third the loom stopped as soon as a thread broke and called for operator attention right away instead of later improving quality. And finally it had a zero

set up time feature built into it for the horizontal threading device. On top of all that of course the sale of its patent for use outside of Japan enabled the start up of the automotive division in the company. All it all it was a spectacular machine. Different models of this machine and other looms make up an entire wing of the Toyota Commemorative Museum of Industry and Technology in Nagoya in remembrance of its vast influence. I highly recommend a visit to the museum if you ever get the chance.

Cutting Tool Set Up Reductions in Machine Shops

A second case that can be made for early set-up reduction work comes from the Honsha plant machine shops of Toyota managed by Mr. Taiichi Ohno after World War II. Upon being appointed the machine shop manager by Eiji Toyoda the cousin of the founder Kiichiro, Mr. Ohno was given the task of improving productivity and reducing cost in his area of control. Both interviews and written accounts in the company's 20 year edition of its internal history note that he the embarked upon a series of experiments in engine manufacturing that were truly revolutionary. Between 1945 and 1955 Mr. Ohno induced workers to run multiple machines while also eliminating the tradition of holding banks of work-in-process inventory.

If that were not enough he and several of his main disciples including Mr. Suzumura, Mr. Mamiya, Mr. Arima, Mr. Watanabe, Mr. Morita, and Mr. Yoshi also improved the way the factory was organized and put manufacturing processes more effectively in the order that the product flowed. This furthered work started by Kiichiro and Eiji Toyoda that was disrupted by the war. In the past the machines traditionally were organized by type such as mills, grinders, lathes, gear cutters, and drills, etc. and were operated by specialists. Where did the inspiration for this all come from? According to accounts by retired Toyota Chairman Eiji Toyoda it came from a 4 inch think manual on flow production and JIT that Kiichiro Toyota created many years before. Mr. Ohno built upon this further with his own refinements. These key leaders also analyzed and standardized work content as well as implemented very basic forms of takt time and pull production ideas they took from the aircraft industry and supermarkets. Supervisor skill set was developed by introduction of TWI training materials from America and emphasis was put on improvement by elimination of waste. What a spectacular ten year period it must have been as the primary elements of the Toyota Production System crystallized inside in the machine shops at least between 1945-1955.

When asked about his inspiration for TPS, Mr. Ohno has made a variety of comments in public and in writing over the years. In his books in Japanese about the Toyota Production System he attributes a lot of his developments as merely natural extensions of Henry Ford's mass production system. In addition he also comments that he learned everything that he ever needed to know from the Toyoda Auto Loom business. In hindsight he viewed the auto loom factory as a perfect little training ground before entering into the bigger machine shops of Toyota Motor Corporation. For example we know that from the Toyoda Auto Loom factory he had a clear model of a moving assembly conveyor line and flow which had been set up by Kiichiro Toyoda in 1927. He had a clear notion of how one person could run multiple processes instead of just one machine which was the norm he found in the machine shop around 1945. Importantly he also had the notion of automatically building in quality and not

inspecting it in later. These points of guiding wisdom from his early days clearly shaped much of his later thinking regarding the direction of improvement efforts in the machine shops of Toyota Motor Corporation.

Relative to set-up reduction Mr. Ohno and his early disciples made some fairly significant changes as well. The normal convention in the machine shop was for one operator to run one machine. In addition the employees each sharpened and set many of their own tools. According to the aforementioned 20 year edition of the company history, in 1949 while altering the pattern of flow and expanding the notion of one man operating multiple machines Mr. Ohno also made another big change. Operators would set their own tools but not sharpen them any longer. Instead a separate tool regrind section was set up inside the plant to prepare and deliver the tools in advance for use. This was merely one of several instances where on-line work was separated and made off-line work in the name of improving machine efficiency. Once sharpened the tools were delivered to the machine and pre-staged for use. In effect it was separating internal operator task time and shifting it to external work to avoid shutting down the machine. Cutting tools are rather small when compared to stamping dies but the effect is the same on production output. According to retired machine shop production manager Mr. Yoshio Oka and others instead of having a machine tool down for 20 to 30 minutes while the operator sharpened and set up a new tool all machines were setting up cutting tools with very low single minute performance by the mid 1950's.

Danly Corporation's QDC Mechanisms

Normally when we think of set-up reduction however our mind tends to dismiss the type of machines described above and it automatically jumps to larger press machines found in stamping operations. Most set up reduction work today often goes by the more specific name of single minute exchange of die or SMED. This was not always the case however in the history of development of set-up reduction. Indeed the term more widely used in the 1960's in Toyota and many companies was quick die change or QDC for short.

Where did QDC come from? As noted author Michael Cusumano points out in his history of the Japanese Automobile Industry, "It is one of the great ironies in the history of production management and technology transfer that the idea of rapid set-up, in addition to the time and motion studies that the Japanese used to cut cycle and idle times, were American. Ohno first saw Danly stamping presses on a trip to the United States in the mid-1950's". In interviews in research books by Japanese authors entitled "Origins of the Toyota System" and "Formulation Development and Transformation of the Toyota Production System" both Mr. Taiichi Ohno and his early disciple Mr. Suzumura gave extensive credit to the Danly Corporation for development of the moving bolster mechanism and other key features for quick die change. These mechanisms greatly aided set-up reduction efforts in the company and are even today described by internal company history books as well as at the Toyota Commemorative Museum of Industry and Technology as revolutionary advances in stamping technology.

I could not isolate an exact date of origin for the quick die change function developed at Danly Corporation. The company still apparently exists as a tool and die maker although it no longer makes machines. Several phone calls and e-mails did not generate a response. From Mr. Ohno's comments to Mr. Cusumano it would appear the technology existed in the U.S. as early as the mid 1950's. Toyota's internal company history records note that 14 of the machines were installed around 1960 for two new lines at Motomachi plant. One of these machines is now on display at Toyota's Museum of Industry and Technology in Nagoya Japan. Along with a description of the moving bolster design and QDC features is a plaque noting that it took $1/10^{th}$ the set up time required by traditional stamping machines! It is no coincidence that as a result Toyota's average die changeover time plunged from over one hour to around 15 minutes in 1962. Individual single minute exchange of die machines were reportedly also in existence at this time. This engineering advancement by an American company is without a doubt a clear candidate for development of set-up reduction techniques. *(Note: I have included some pictures of an actual Danly machine and the set up reduction explanation displayed in the museum at the end of a separate interview summary with Mr. Katsuya Jibiki of Toyota's press shop).*

Toyota Press Shop's Kaizen Efforts

In parallel to the introduction of the Danly machines to Toyota there were also ongoing daily improvement efforts in the Honsha press department. Once Mr. Ohno had successfully converted his engine, transmission, and chassis lines to the newer style of production that he envisioned he was rewarded with another promotion in the company to plant manager. Now in addition to the machine shops Mr. Ohno also picked up responsibility for the casting, forging, and stamping shops in the company. He now had responsibility for all the primary elements of manufacturing in the company and was a formidable presence. As such he was in a position starting in the early to mid 1950's to begin rolling out his methods more broadly to other areas of the company.

One such shop was the Honsha press department where Mr. Katsuya Jibiki worked for 38 years as an operator of a press, a supervisor, and later as division manager. Mr. Jibiki notes that pressure to reduce set-up time existed in the press shops before the mid 1950's when he first joined the company. Frequently parts were needed downstream in welding or assembly as the presses had been making either the wrong type of item or the wrong quantity. Mr. Ohno insisted that parts be put on a replenishment schedule and a basic form of a supermarket be implemented. This alteration according to Mr. Jibiki in addition to targets requiring improved machine efficiency in turn put immense pressure on the press department to changeover stamping dies more rapidly than they had in the past.

According to Mr. Jibiki, in the Honsha press shop in the late 1950's there were about fifty stamping machines that were not in very good condition. The average changeover time on each varied from one to four hours depending upon the size and condition of the machine. Using a combination of operation instruction sheets and basic time studies of the process the department members observed there was much waste in the way they conducted changeovers and they started making small improvements. These changes included using carts for moving

the dies as well as for loading and unloading operations. Adoptions of clamps and cylinders, visual markings, elimination of bolts, addition of locating pins, and standardization of die heights, as well as many other gradual improvements were added according to Mr. Jibiki. Many ideas were adapted from the Danly machines. The net effect of all this was large however as various published TPS timelines indicate the average changeover time in the press shop was reduced to 15 minutes in 1962 and down to a mere 3 minutes in 1971. It is difficult in hindsight to sort out the effects of the newer Danly style moving bolster type QDC machines and the set up reduction efforts on the older machines. Both were no doubt of great influence in reducing the noted average changeover times in the company.

The Brazilian Forging Press Influence

Taiichi Ohno authored two main books in Japanese about his management experiences in Toyota. One of them was called "Genba Keiei" or "Workshop Management" in English. I had glanced through the contents of this book before on several occasions but a more recent reading caught my eye. In a chapter of the Japanese version he wrote a section called "Learning Set Up Reduction in Forging from Toyota of Brazil". Most people are not familiar with the plant in question but it is actually Toyota's first plant built overseas in the late 1950's. The product produced was the Land Cruiser and the volume was an incredibly low 2-3 vehicles per day. It was also called in various circles at the time the world's smallest automobile plant.

Due to the extremely low volume of the facility it was initially equipped with older used equipment from Japan and other Brazilian sources at the time. Not a lot of money could be spent on extra capacity or equipment or inventory either due to constraints. As a result only one forging machine was arranged for the plant and in order to utilize the machine fully a total of 60 different part numbers were scheduled to be run on the forging press. The plant quickly realized though that it had a problem. In forging operations a normal lot size at the time was at least about 1,000 pieces and often many more. With an initial volume of only 2-3 vehicles per day however running 1,000 pieces would require purchasing material far in advance of needs and build up work in process inventory that equated to years of material. To make the situation worse outside companies were not willing to make items in such small order quantities either so Toyota was stuck with an old machine that required a minimum of an hour or more to changeover and 60 different forging part numbers to build.

The vast amount of work in process inventory was not acceptable from a financial point of view or an operational one to Mr. Ohno. He initially ordered the plant to start making 8 changeovers per shift and to forge no more than 15 parts at a time. The plant complained that this would mean basically 8 hours of changeover work per shift and argued with him. Mr. Ohno states that he told them to reduce changeover time to 15 minutes and increase the number of changeovers per day as ordered. This improvement would mean that in one hour about 2 changeovers could be performed and 2 part numbers could be run. In an eight hour shift about 16 part numbers would be run or in four days every one of the 60 part numbers would be run and the inventory amount kept down to less than one week. Eventually with much effort the set-up time was reduced to less than 10 minutes and even beyond Mr. Ohno's

target. As a result he says several Japanese from the forging shop in Japan were sent to look at this machine to study its efficiency.

Shigeo Shingo and SMED

The most popular name when it comes to set-up reduction however is probably Mr. Shigeo Shingo. Due to his book that was originally published in 1983 and translated into English in 1985 the world outside of Japan learned that there was a method and a reason to decrease lot sizes on stamping presses and other machines. The lessons were clear and logical. Separate internal work from external work. Move as much of the internal work to external work as possible. Eliminate needless fastening and minimize the use bolts. Use quick clamp devices. Reduce the need for any adjustment work. Standardize the method and improve it continuously. It was good sound advice and remains so to this day.

Mr. Shingo depicts the development of his SMED method in the following fashion. First he notes two influential pre-events. The first was in 1950 at Toyo Kogyo (Mazda) where he realized there were fundamentally two types of work in press operations: internal set-up work and external set-up work. In 1957 he got a chance to test his theory at the Mitsubishi Heavy Industry ship yards in Hiroshima. He encouraged the facility to set up a second planing table so that external work could be done in advance of needs. This eventually helped to increase productivity by 40% and help cut ship build time from four months to two months by his estimation.

Mr. Shingo's crowning moment with SMED development however is in 1969 when he was able to put the pieces all together and reportedly helped reduce changeover time on a 1,000 ton press at Toyota's Honsha plant from four hours to one and a half hours. He was initially satisfied with that level of improvement but states that he was "dumbfounded" in his own words when further instructions came from Toyota management to reduce the set-up time from that level to three minutes. After the initial shock wore off he states that a flash of sudden inspiration occurred to him and he realized a further chance to shift more of the internal work to external work and scribbled several improvement ideas on a board. With this event a "systematic technique" for achieving SMED was born according to Mr. Shingo. Also he states that the technique then spread from this event throughout Toyota and then other plants around the world.

It is unfortunately unclear from the passage in his book whether or not Mr. Shingo already knew that average set up time was less than 10 minutes in the press shops of Toyota in 1969 on the vast majority of machines (the company average was 15 minutes in 1962 and a mere 3 minutes in 1971). He does not mention the previous set-up reduction work done by Mr. Jibiki or the many others at Toyota either. It is not even clear he was aware of new QDC technology from Danly Corporation that was in full use at the newer Motomachi stamping plant at Toyota. It would certainly appear from his comments that he does recognize any of those items at the time but then perhaps since he is just claiming to have formulated a "systematic technique for analysis" then that is all he meant. There is also a brief section in his book with a truncated passage quoting from Mr. Ohno based upon a speech he gave to the

Japan Management Association. In the speech from 1976 Mr. Ohno gives a polite remark to Mr. Shingo acknowledging him for his role in helping "advocate" the necessity of set-up reduction many years earlier. He makes no specific mention however of Mr. Shingo doing any such actual work at Toyota.

Nissan and other companies

I did not look very far or wide to study other companies with their history of set-up reduction. It strikes me that in reality this is a fairly common sense topic and one where the principles have been applied in other settings in many other locations. Michael Cusumano notes in his book on the history of the automobile industry in Japan that Nissan and other companies were doing improvement activities and set-up reduction work in parallel to Toyota around the same time. A brief check with Bill Laske a former Training and HR manager for Nissan in Japan indicates that similar set-up reduction work was going on in Japan at roughly the same time and pace as Toyota. It was also completely independent of any assistance from Mr. Shigeo Shingo or any other consultant for that matter. I suspect the same is true in other companies as well. This is certainly the case of equipment manufacturer Danly Corporation and its QDC inventions. The notion of reducing set-up time to improve machine efficiency is a pretty straightforward insight that a few different industrial engineers and equipment designers have probably come up with over the years.

Summary

From this brief account you can see why there is no clear-cut answer regarding the person who first developed the methods for set-up reduction. The need for set-up reduction was likely obvious to many different people from the standpoints of machine availability, productivity improvement, minimizing capital expenditures, and reducing work-in-process, etc. Thus, it should not be surprising that set-up reduction, as we know it today, was the product of many people's efforts. Even so, there are key events which are important in tracing the origins and development of set-up reduction.

The case for both Sakichi's G-Type Loom and Danly's stamping machines with moving bolsters and other quick die change mechanisms are the strongest cases from a legal point of view as they both involve specific patents and invention records. Other cases may exist in other industries as well. Both of these machines suffer somewhat however from an influence point of view. The G-Type loom only affected Toyota internally and its influence was then filtered and passed along in later years. The Danly machines and its quick die change function for whatever reason did not catch on in the U.S. or the rest of the world as much as one might think. Mr. Ohno himself hypothesized in his discussions with Mr. Cusumano that quick die change features were just not needed for the type of mass production manufacturing being practiced in the United States at that time and thus not more widely adopted. As Bob Emiliani Professor of Manufacturing at Central Connecticut State University pointed out to me as well the overarching influence of economic order quantity logic and its implied impact on scheduling decisions also would have been a large influence on American management's thinking.

The case for the Brazil plant is an excellent one except that I thought there was somewhat insufficient detail in Mr. Ohno's depiction. I contacted Mr. Gilberto Kosaka a former manager with Toyota of Brazil for further insight. He confirms the outline of the story, the number of parts produced, the changeover reduction to less than 10 minutes, and dates it around 1970 in terms of history. The two Japanese who also worked on the press he identified as Mr. Haraguchi and Mr. Maeda of Toyota. There were no other external advisors beyond the Brazilians and Toyota people involved and hence it was truly an impressive development on a large forging machine all by themselves. This improvement in turn helped drive the forging shops in Toyota Japan to apparently reduce their set up times further as well. It is very likely Toyota's first sub 10 minute changeover machine in forging operations at least.

Internal improvements at Toyota in the machine shop and the press shops in the 1950's and 1960's have to be recognized as great applications of set-up reduction concepts no matter how you view them. Interestingly however no one in Toyota has ever to my knowledge claimed they invented the notion of set-up reduction. Indeed they usually go to great lengths in order to put praise on others or merely state it as an obvious extension of improving machine efficiency. In interviews a dozen or so different Toyota managers, engineers, and supervisors were consistently mentioned as having greatly contributed. None the less despite their humility this generation of workers and managers starting in the 1950's and through the 1960's mastered the actual practice of set-up reduction on many different types of machines beyond than any other similar manufacturing company in the world at that time.

The last contributor to the equation is Mr. Shigeo Shingo whose role in set-up reduction and SMED puzzles me more than when I started preliminary investigation into this topic. His self depicted accomplishment of creating SMED in the press shop of Toyota in 1969 is directly at odds with Toyota's documented history and recollections of people from the department. Mr. Jibiki an area supervisor at the time and later manager of the press department can't even recall such a described workshop taking place in 1969 and speculates that it was perhaps just some type of general discussion that was held. Either way he views it as fairly insignificant to Toyota's internal efforts no matter how it actually occurred since it was so late in the actual history of set-up reduction at Toyota. Mr. Isao Kato who organized the majority of Mr. Shingo's visits to Toyota for training courses commented that Mr. Shingo was just unlikely to be aware of the actual extent of set-up reduction in Toyota since he was not that involved in the daily improvement efforts. Thus when he wrote his SMED book in 1983 he just didn't know enough of the historical details to tell the whole rather complicated sequence of actual events inside Toyota. Unfortunately only Mr. Shingo, who passed away in 1990, could clarify this account I'm afraid.

In the introduction to his book on SMED however in the English version, Mr. Shingo left us some pretty clear comments. He notes that a host of books have come out in recent years before his with names such as "Quick Die Change" and "The Instant Setup". He also notes that Japanese industrial engineers have long understood that reducing set-up time is a key to developing a competitive industrial position. In his words he simply sets out to present the

reader with practical examples, some better how to advice, and the theory behind the method. This statement strikes me as both accurate and the actual intent of his well written book.

With the benefit of some historical perspective it is clear that Mr. Shingo did not quite invent the notion of set-up reduction or even create the first sub 10 minute changeover machine at Toyota as is often mistakenly assumed in the West. However in terms of influence outside of Japan in particular let us not forget that he ranks higher than the other cases mentioned for the simple reason that his book on SMED was the first translated into English at a critical time and thus affected many companies around the world. He also personally made many trips to the United States and other countries to promote the method outlined in his book and conduct workshops. For this point alone he still deserves a lot of credit and acknowledgement for both advocating and furthering the advancement of the set-up reduction methods in manufacturing.

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Jibiki, Katsuya. Mr. Jibiki is a retired manager of Toyota Motor Corporation in Japan from the Honsha Press Department. For 38 years he worked as a production operator, set up team specialist, production supervisor, and eventual division manager of the area. Later he became a General Manager of Production at Toyota Tekko a supplier of metal and stampings. He then also served as an advisor to the board of directors.

Kato, Isao. Mr. Kato is a retired manager of Toyota Motor Corporation in Japan. Mr. Kato spent most of his career in training and development related activities. He also had a brief stint in the company's Operations Management Consulting Division. For years he aided Mr. Shigeo Shingo in teaching an internal course at Toyota called the P-course. Mr. Kato also acted as the internal master trainer for topics such as the TWI courses, Standardized Work, Kaizen, and many others as well.

Kosaka, Gilberto. Mr. Kosaka is a retired manager from Toyota of Brazil and an active consultant in the area of TPS. In e-mail correspondence he was able to clarify and confirm many of the events depicted in Mr. Ohno's description of set up reduction work in the forging shop in Brazil as well as provide additional information.

Oka, Yoshio. Mr. Oka is a retired production manager from Toyota Motor Corporation. Mr. Oka worked in engine production in a variety of positions and facilities for Toyota for 40

years. He worked as an employee, Team Leader, Group Leader, Foreman, and Manager in Honsha, Kamigo, and Shimoyama machine shops.

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