OPTIMIZATION OF A STEEL PIPE MANUFACTURING SYSTEM TO IMPROVE OVERALL EFFECTIVENESS

Md. Shahriar J. Hossain
Ph.D. Student
Faculty Advisor: Bhaba R. Sarker

ABSTRACT

Steel pipes are treated as a vital element for residential or commercial buildings, oil-gas transportation systems and many other industrial applications around the world. A steel pipe manufacturing process can be broadly divided into four phases: feeding, forming, inspection and finishing. Different facets of these four phases are investigated in this research to minimize the cost of production and to increase throughput and yield of the overall system.

Feeding buffer capacity: Continuous seam welded pipes are produced from steel strip coils. The steel strips are first uncoiled and straightened, then welded with the end of preceding strip to maintain the process flow. In order to avoid any disruption of production due to this joining operation a buffer inventory is held in between joining and forming stations [Figure 1].

![Figure 1: Buffer storage following the forming station.](image)

Allowable buffer inventory directly depends on the strip joining time. When feed rate of the line is given by \( v \) feet/hour and the coil accumulator (buffer) can accommodate \( B \) feet (buffer size) of steel strip, the operators at the joining station gets \( B/v \) hours to complete their job. If they fails to complete the joining process by this time, the whole line has to be stopped. High buffer inventory provides higher flexibility of time to carry out the joining operation. However, increasing buffer capacity means extra investment. The time required for the joining process depends on several process parameters including thickness of the steel strip, human factor and some random variabilities. Hence, the problem is to find an appropriate buffer capacity that can minimize total cost of the line. In this research a total cost function is proposed to be formulated and solved optimally, considering the issues of line stoppage, buffer storage investment and strip joining parameters.

Pipe sizing in forming stage: Pipes are manufactured in different sizes and shapes depending on the customers’ specifications. For a particular pipe production line the pipes are supposed to be maintained a standard length (\( L_a \)). Unavoidably various types of production defects are found to occur at the pipe forming stage. In-line inspection helps determine some visual or dimensional inaccuracies. Commonly, occurrence of defects follow Poisson process. Randomly generated defective spots can be reworked on-line, or off-line depending on the cost or feasibility of the rework. When a defect is not reworkable on-line, or an on-line rework disrupts the smooth flow of production, the defective pipes are sent to an off-line rework station. In many cases, the defects are not reworkable or incurs high rework cost even at an offline rework station. In those cases the defective portion of the pipe is scrapped, though a huge cost is sunk due to the material and processing of the scrap.

![Figure 2: Substandard pipes from defect free portion.](image)

Sometimes, some buyers have willingness to buy some substandard length (\( L_b \)) of pipes at a different price tag, in order to avoid cutting cost at buyers’ facility. This demand may create more profitable opportunity for the manufacturer to deal with the defective portion. A defect free portion (with length \( L: L_b \leq L \leq L_a \)) of the pipe can be processed for producing substandard pipes by avoiding reworks [Figure 2]. Thus, another way to deal with the defects is to cut off the defective portion into small substandard pieces. Now the problem is to find the optimal rework policy (rework or scrap) and cutting length of the defective pipes, so that the profit can be maximized while inline inspection facility is devised for effectively detecting some specific types of defect. In order to address this problem, a non-linear profit function is developed in terms of cost parameters and desired length of pipes. Indicating alternative decisions with binary variables, this profit function and relevant constraints form a non-linear integer programming (NLIP) problem which is solved both optimally and heuristically.

Inspection and rework queue: The standard and/or substandard pipes are finally sent to the inspection stations for detecting any nonconformities. Repairable defective pipes are sent to the off-line rework station and then fed...
back to the inspection station for re-inspection. The unrepairable defective pipes are scrapped. Thus a queue of manufactured pipes is generated in front of the inspection station, and another queue of inspected pipes are generated in front of rework station. The queuing systems for inspection and rework stations are intertwined together.

In general, the inspection, and repair times follow some probability distributions. The average arrival rate of pipes at the inspection station is equal to the production rate \( P \) of the pipes plus average service rate \( (\mu_i) \) of the repair station. If the expected proportion of defects detected at the inspection station is given by \( p_d \) among which \( p'_d \) proportion is repairable, then the average arrival rate at the rework station will be \( p'_d \mu_i \), where \( \mu_i \) is the average inspection rate [Figure 3]. Thus, \((1-p'_d)\mu_i\) units of pipe go to the finishing stations(s).

![Figure 3: Layout of inspection and rework facilities.](image)

The capacity of the inspection or rework station(s) can be increased by adding extra server(s), which will eventually add extra investment. On the other hand, the factory has a certain floor space constraint to accommodate additional inspection or rework server(s), as well as the pipes in the queues. This constraint limits the number of inspection/rework server(s) and the length of each queue. By increasing the capacity of the inspection and/or rework stations the length of the queue can be minimized, which consequently saves some floor space for work-in-process inventory. Thus the problem is to figure out the appropriate number of inspection and rework server(s) that minimize the total cost. To achieve this goal, the queuing system in Figure 3 is proposed to be formulated for the total cost based on queuing theories, in terms of inspection and rework queue lengths and relevant constraints. The model can be solved to minimize the total cost to obtain optimal number of server(s) in the inspection and rework stations.

**Allowable stopping time and finishing tool inventory:** In steel pipe manufacturing industries cutting tools are used for removing extra materials from the welding zone in order to achieve a uniform and smooth finish. Additionally, polishing the inner and/or outer surface of some pipes are necessarily done as a part of finishing operation [Figure 4]. In both cases, when a tool fails the whole production line needs to be stopped. This stoppage leads to loss of productive time and material. Using identical multiple tools in the tool magazine can minimize the number of stoppage for changing the tools in the magazine. However, this option adds extra cost for operating a bigger tool magazine. The multiple tool facilities and joint tool replacement policy can enhance the surface quality as well by minimizing tool failure during operation. Whereas, the removal of tools from the tool magazine before the end of their life results unutilized portion of tool life, which eventually increases the total number of tools required in a year. Thus, the objective of this phase of research is focused at determining the appropriate stopping time for reloading the tool magazine, optimal size of the magazine and the ordering size of the tools, which eventually minimize the total cost for cutting or polishing tools.

![Figure 4: Polishing operation schematic.](image)

A total cost model is developed for the tools in terms of tool life distributions and different cost parameters. The model is optimally solved to find out the appropriate usable time for a tool magazine for different magazine size, while minimizing the total cost. Numerical results show that the optimum total cost reduces with the increase of the magazine size. Results also show that the expected number of tools required in a year reduces with the increase magazine size.

Each of the four phases of this research aims to enhance throughput and yield of the steel pipe manufacturing system. The optimization models eventually reduce the overall cost of the system and increase profit. The models are effectively applicable in any continuous pipe production facility which involves different quality inspection and rework issues.

**REFERENCES**


