Development of a Tunnel-Boring Machine: Saved the Workers and the Company
Harsh Wardhan Aggarwal
Integral Screw Industries, India

Scope: Integral Screw Industries (ISI) is a mid-size, steel pipeline company based in India. In 2010, the company was tasked to lay underground water pipelines for the construction of Delhi Metro Railway project in New Delhi, India. For a project cost of INR 100,000,000 (USD 2 million), the company had to lay a 1m (3'3") – 2m (6'6") diameter pipeline at a depth of 7m for a total length of 120m in a time frame of 6 months. The process was mostly mechanical where workers (average height 5'8") had to dig a trench (7m deep) and lay a 1m diameter pipeline therein. Due to the height difference (pipe diameter was much less than the average worker height); the workers had to bend down for an extended period of time which caused unsafe work conditions. The human factors team led by the author developed a tunnel boring machine (TBM) by using old gears and gear train which resulted in increased productivity, and improved the work conditions at the facility. In the end, the use of human factor and ergonomic (HFE) principles increased the profit margin for the project by more than 30% (which was previously recording a $50,000 loss/day due to worker safety and downtime).

Project Organization: Due to relaxed worker safety laws and the availability of cheap labor, many companies in India rely heavily on manual labor unlike other developed countries. These laws and outright neglect for the worker safety leads to hazardous conditions for the workers which leads to injured workers resulting in company downtime. The project studied in this paper is a pipeline laying project which required around 50 workers to dig a 100m tunnel at a depth of 7m. The varying diameters (dia) of the tunnel (3'-6") caused the main challenges for the safety of the diggers. Since the tunnel boring was done manually, the workers (with an average height of 5'8") had to bend down in order to dig a 3' dia tunnel. Extended work hours and continuous bending for more than 8-10 hours resulted in injury to around 30 workers in the first 10 days of the commissioning of the project. This led to increased downtime which resulted in losses at a rate of $50,000 per day. This loss rattled the top management. After a thorough work analysis, the human factors team (which was non-existent at that time in the company) made up of the
author (industrial engineer intern), project manager (design engineer) and the CEO (mechanical engineer) of the company, pin-pointed the constant bending of the workers as the primary cause for worker injuries. After a market research of tunnel boring machines (TBMs) showed that an import of a similar machine from the US would cost 20% of the overall project cost (more than INR 20,000,000), the company decided to develop an in-house TBM. The human factors team focused on the physical aspects of the problem which included; the height difference between an average worker and the pipe diameter, constant need of clearing up the mud from the tunnel, overuse of workers (15 workers used to work in a single shift) and improper tunnel cutting (due to the manual digging of the tunnel). In the second step, the team conducted a market survey for used parts which were needed to build the TBM. A total cost-benefit analysis was conducted while keeping the human factor principles in mind and a final decision to build the machine in-house (at a cost of INR 500,000 or $10,000) was agreed upon. The team built the TBM in 10 days and conducted a pilot test of the same. The machine was a success as it reduced the total workers from 15 to 4 (who were tasked to manage the different parts of the machine), the productivity increased (earlier 15 workers used to dig 5-6m whereas the TBM created a 12m tunnel/day), and most importantly, the workers were safe (the company recorded a 0 injury project after the implementation of the TBM).

**Project Phases:** The various project phases used in the human factors project (as detailed in the project organization) were basic evaluation, root-cause analysis, market research, ergonomic need-want analysis, actual machine design, testing and evaluation.

**Conclusion:** It is usually difficult to quantify the benefits of using HFE principles in unconditional work conditions. Since, the major benefits (worker safety in this case) are noticed only after a project suffers through some challenges, it becomes the biggest hurdle for human factors professional to convince the management about the importance of HFE principles. This project suffered through these challenges early enough which helped the author to conduct a cost-
benefit analysis and develop an ergonomic plan to implement worker safety and thus increase productivity of the company.