Increasing and Sustaining Heavy Haul Wheel Set Maintenance Operations through Computer Controlled Integrated Manufacturing

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1.0 Introduction

"Back Shops" or maintenance shops play a critical role in maintaining and improving capacity in heavy haul operations. As heavy haul operators develop and implement more processes and methods for increasing capacity, the ore car maintenance wheel shop can often become a constraint to further improvements. The graph below shows the tremendous demand within the iron ore industry and in the corresponding need to increase supply. [1]

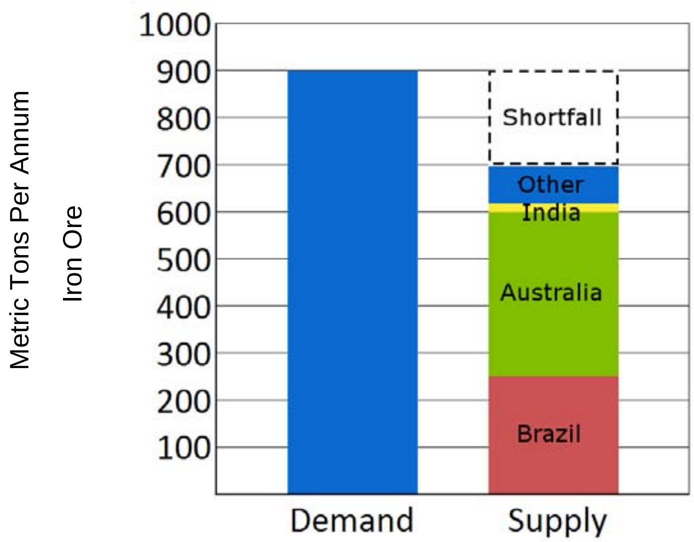

Fig. 1. Iron ore demand from China versus worldwide supply

Across a variety of heavy haul operators, many of the same bottlenecks or constraints can be found inside the ore car wheel shop. These bottlenecks are evidenced by significant wheel set stockpiles or inventories sitting in the shop often nearby key processes such as wheel set assembly or wheel set re-profiling. Wheel set stockpiles are non-productive assets, not adding value to moving product to its ultimate destination.

Two of the most frequent constraints found in a heavy haul wheel shop are wheel set re-profiling and wheel set assembly. The majority of incoming wheel sets are re-profiled. Ensuring high productivity for re-profiling is a simpler challenge compared to coordinating the multiple variables affecting assembly of new wheel sets. These multiple variables are axle wheel seat surface finish, diameter and taper wheel bore surface finish, diameter and taper, constantly changing tool wear at each metal cutting process, and lubrication of axle wheel seats and wheel bores. See Fig. 2.

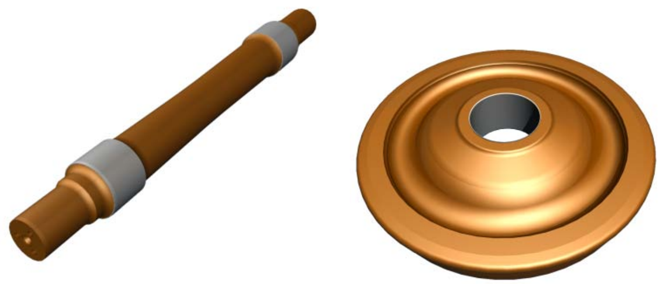

Fig. 2. Axle wheel seat and wheel bore areas shown in gray

All of these variables ultimately manifest themselves in whether or not a successful force vs. distance graph or mounting graph is produced at the wheel set assembly/mounting press.

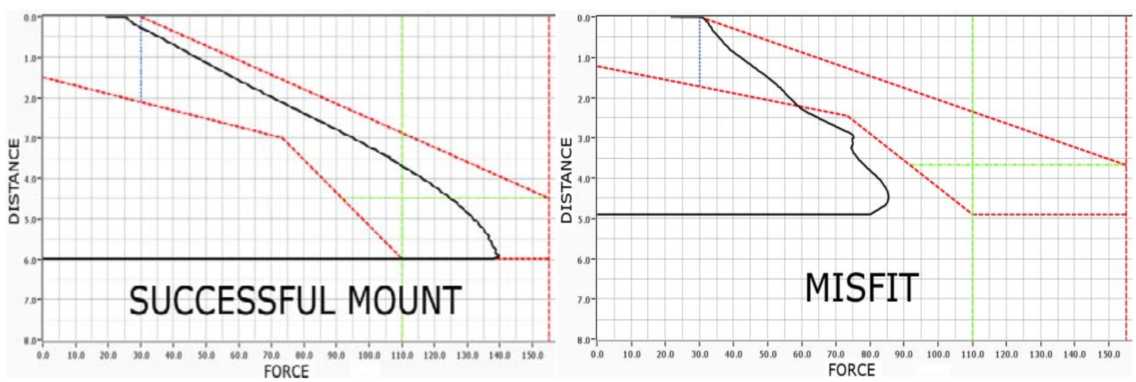

Fig. 3. Successful versus Unsuccessful mount graphs

This paper will explore strategies in deploying robust process technology, electronic sensors and networked machine tools in the modern heavy haul maintenance wheel shop. By successfully integrating these technologies, the multiple variables in producing wheel sets can be controlled and utilized to improve yield and thereby increase available wheel set capacity. Primary focus will be on maintenance of wheel sets that have to be disassembled due to wheel defects, lack of service metal remaining and other factors requiring demounting.

Integrating machine tools, sensor and measurement technology is not a new concept. Naumann already outlined such a concept during the 1999 International Heavy Haul Conference in Moscow, Russia [2] applied to wayside wheel set defect detection and related strategies for proactive wheel set maintenance. Later in 2002, Naumann applied this concept to proactive underfloor wheel truing technology. [3]

2.0 Heavy Haul Maintenance Wheel Shop Process Description

The Association of American Railroads (AAR) Manual of Standards & Recommended Practices Section G-II [4] offers a robust process for wheel set maintenance by emphasizing reduction of the number of controlled parameters through focus on satisfactory mounting graphs as shown in Fig. 3 above. The AAR process does not specify target diameters for wheel bores or axle wheel seat diameters nor does it specify surface finish parameters for wheel internal bores or axle wheel seats. Alternative processes to AAR often involve controlling additional quality parameters such as target diameters for machining processes (e.g. axle wheel seat and wheel bore diameter), and specifications for surface finish (e.g. bore finish and/or wheel seat finish). The force and distance graph can be thought of as the final quality control document for the mounting process.

The following is a brief description of the wheel set process flow found in Fig. 4 which is a layout of an automated heavy haul wheel set maintenance shop currently under construction.

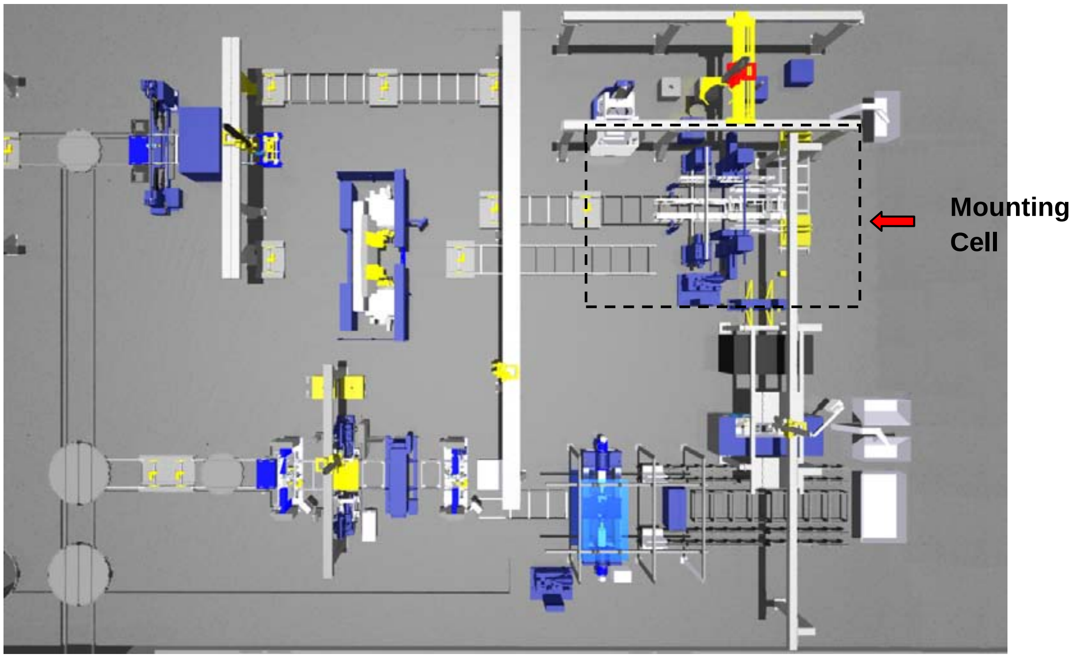

Fig. 4. Rendering of automated heavy haul wheel set maintenance shop

2.1 Inspection and Sorting Tread Turns versus Demounts

As used wheel sets enter this facility, they are prepared for inspection by an operator who removes the bearing box end caps. There is a total of only 5 human operators in the facility. The threaded bolt holes and center holes are visually inspected for damage while the roller bearings are inspected for wear. Axle serial numbers are entered into the Supervisory Control and Data Acquisition (SCADA) system. The AAR process requires that wheel sets for interchange service have their roller bearings removed upon entering the wheel shop whether or not the wheel sets are re-profiled. The shop shown in Fig 4 is for a captive Australian railway; therefore, it is not necessary to remove all bearings. If the wheel set is acceptable it is passed on to a wheel set metrology machine that measures key parameters of the worn wheel set. The decision to either re-profile the wheel set or demount the wheels is made within this machine. The wheel set is then ejected to the bearing demount press where both bearings are simultaneously removed and a robot palletizes the used bearings for shipment back to the bearing manufacturer. Wheel sets then progress to the bearing journal cleaning machine where steel wire brushes automatically clean and remove any grease from the roller bearing journal surfaces. The wheel set then moves to a bearing journal inspection machine where key bearing diameter measurements are made to ensure the bearing seat or journal diameter is acceptable to reuse this axle. Wheel sets requiring re-profiling are transferred by an automated gantry to the wheel set buffer area awaiting transfer to the portal wheel lathe. Here the wheel sets are re-profiled by an automated computer controlled (CNC) machine and then move on to ultrasonic inspection, roller bearing mounting and finally end cap installation.

2.2 Axle Reclaiming

If the wheel sets require demounting they are moved via automatic handling from the wheel set inspection line to the wheel demount press. The automatic wheel demount press removes the wheels from the axle and the wheels are sent to scrap bins and removed from the shop area. Axles are then stored in a buffer area awaiting retrieval by an automated overhead gantry robot that transfers the axles to the axle lathe. Every axle's wheel seats are turned in order to remove any scoring as shown in Fig. 5 below and to achieve a consistent positive taper in the wheel seat of approximately 25 µm. The axle is then picked up out of the lathe and transferred to the axle inspection station. A complete ultrasound and magnetic particle inspection is performed along with other visual inspections per AAR Manual of Standards & Recommended Practices Section G-II. [4]

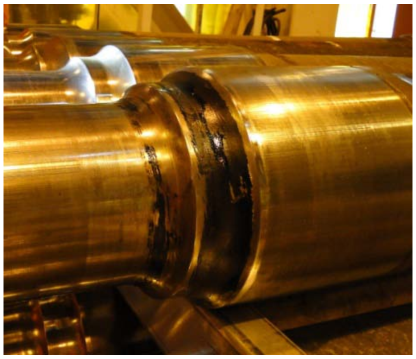

Fig. 5 Axle Wheel Seats with some scoring from Wheel Removal

The axle is then sent to the wheel seat measuring station where the wheel seat diameters are measured. These measurements are automatically transferred to the wheel boring area where the wheel bores are finish machined to an interference fit of approximately 200 µm with the axle wheel seat. The wheel boring machines automatically generate a taper (this is pre-set in the wheel boring machine at the time of assembly at manufacturer's facility) in the wheel bore conducive to generating an acceptable wheel mount. This taper is approximately 25 µm. Once both wheels have been finish machined/bored the wheel bores are lubricated, the axle wheel seats are lubricated and then all components are transferred to the wheel mounting cell.

2.3 Wheel Set Assembly

Within the wheel mounting cell, two primary stations exist; pre-mounting and mounting. In the pre-mount station wheels are pressed, with relatively low force, a short distance onto the axle wheel seat. The pre-mount station's primary purpose is to align geometrically the wheels to the axle. The mounting cell shuttle cart then moves the pre-mounted assembly to the mounting press for final assembly. The mounting press electronically measures the wheel set for correct "back-to-back" measurement and electronically monitors and records the force and distance of the final mounting process. An example of a force and distance graph on the right is shown in Fig. 3 above. The dotted green line and red lines across the graph represent the minimum and maximum mounting tonnage. The AAR template is shown in red linear lines. The black line represents the actual mount. Because this mount is not at all times within the AAR template, the mounting graph is labeled a MISFIT.

3.0 Process Monitoring/Closed-Loop Production Control System

Improving capacity of the heavy haul wheel shop can be achieved by the following:

- Identifying key parameters that must be actively controlled (See Table 1 below) in order to produce an acceptable mounting graph and controlling these parameters via cost effective sensors and measurement technology
- Identifying parameters that can be passively controlled (See Table 1 below) in order to produce an acceptable mounting graph and ensuring these are controlled by inherit machine performance
- Applying a Lean/Pull manufacturing strategy so that key processes in the wheel shop replace only what has been consumed and only what is immediately deliverable. [5] For the shop shown in Fig. 4 above the mounting cell pulls wheels and axles from upstream processes according to when the mounting cell is ready for the next set.
- Design and Implementation of a Supervisory Control and Data Acquisition (SCADA) system focused on monitoring and controlling key processes in the shop.

3.1 Active and Passive Quality Parameters

Active parameters are those controlled in real-time by machine or supervisory computers/controllers. Passive parameters are those designed into or built into a machine or other device or an indirect result of how a machine is set-up. Passive parameters are not controlled in real time by computers or controllers.

Parameter	**Active Control**	**Passive Control**
Interference Fit	•	
Wheel Boring Tool Wear	•	
Axle Wheel Seat Lubrication		•
Wheel Bore Lubrication		•
Axle Wheel Seat Finish		•
Wheel Bore Finish		•
Wheel Bore Taper		•
Axle Wheel Seat Taper		•

Table 1 Parameters Affecting Quality of Wheel Mounting Graph

3.2 Process Control of Active Quality Parameters

Fig. 6 is a control diagram demonstrating key active and passive parameters/variables critical to monitor, integrate and control the wheel mounting press process.

As worn wheel sets are demounted and the axles reclaimed, the SCADA system is continually monitoring the wheel mounting cell. This cell acts as a KANBAN or trigger to initiate the axle reclaiming and wheel boring processes. Strategic buffers are located within the axle reclaiming process in order to provide a staging area until a more critical process calls for a component to progress forward. In reference to Fig. 6, the Kanban/wheel mounting graph, is shown at the top right. There is a direct information feedback loop from the wheel mounting graph back to the interference fit generated at the wheel boring machines. This interference fit is actively controlled and generated by measuring the axle wheel seat diameters of the reclaimed axle and then generating target wheel bore diameters which result in a 200 µm interference fit.

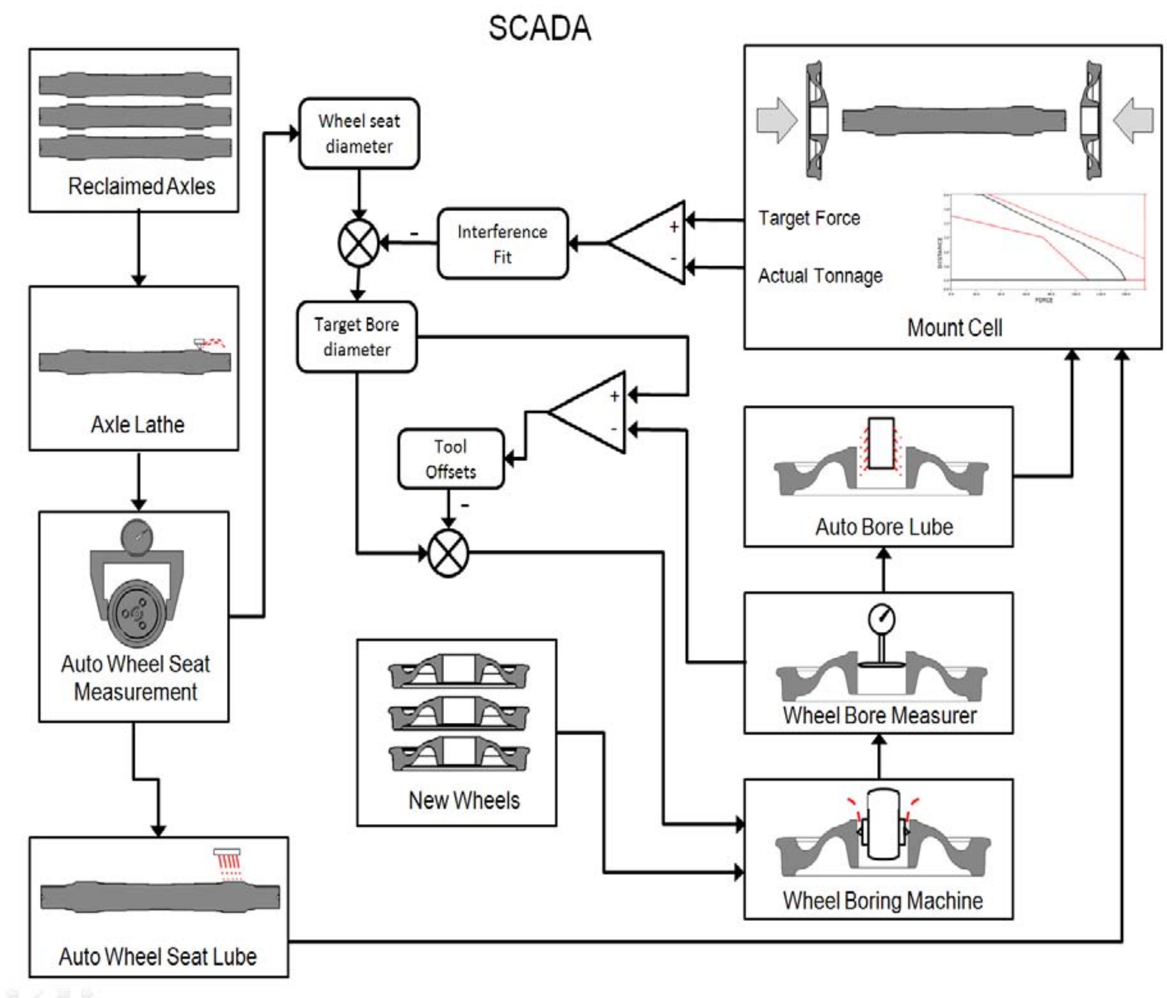

Fig. 6 Process Control Diagram for Closed Loop Wheel Set Mounting

Within the wheel boring process another active control feedback loop exists to control for cutting tool wear at the wheel boring machines. This is done by measuring the bore of the wheels after processing in the wheel boring machines. The bore measurement information is automatically and actively used to adjust for any tool wear by adjusting tool offsets so that an acceptable mounting graph can be obtained.

Additional passive parameters important to successful wheel and axle assembly are shown on Fig. 6 such as automatic axle wheel seat lubrication and automatic wheel bore lubrication. By utilizing lubrication systems that automatically meter and dispense the mounting lubricant to the wheel bores and axle wheel seats, the wheel set assembly process is further optimized.

4.0 Supervisory Control and Data Acquisition System

The SCADA within the wheel shop controls and executes the following decisions:

- optimal time to release materials for processing
- when to lubricate wheel bores and axle wheel seats to prevent negative effects from drying time adversely affecting production of an acceptable mounting graph.
- when to adjust cutting parameters/tool offsets at the boring machines
- machine fault monitoring
- video monitoring of critical machines, cells and other areas where maintenance technicians benefit from visual monitoring/surveillance.
- In cold climates the SCADA monitors and prevents components from being assembled that differ greatly from each other in temperature.

5.0 Summary and Conclusions

Applying the above described integrated process technologies and cost effective sensors [6] to heavy haul maintenance wheel shops substantially improves capacity by increasing yield and reducing misfits during the mounting process.

After reviewing over 50 different heavy haul maintenance wheel shops located in North America, Brazil, Russia and Australia it was observed that misfit ratios were typically 10% of the total mounting cycles or greater. Many shops do not consider a wheel set that does not mount correctly to be a misfit if it can be easily de-mounted and then circulated back into the wheel shop process. Yet, this must be considered a misfit as it reduces wheel shop yield and capacity by not mounting correctly the first time. Wheel shops deploying the integrated computer controlled process technologies described in this paper, experience no more than 0.1% misfits, or 100 times better than most traditional wheel shops.

Of course, additional benefits such as manpower reduction exist and are substantial since 5-6 operators and 3-4 maintenance technicians per shift are all the manpower that is required to run a computer integrated wheel shop. In contrast a traditional wheel shop requires 25-30 operators/ technicians per shift.

For a heavy haul maintenance wheel shop processing 20,000 demounted and remanufactured wheel sets per year, the difference between 10% misfits and 0.1% is substantial. At 10% or 2,000 misfit wheel sets per year and 20 minutes per misfit to knock down, reclaim the axle, possibly bore out wheels to a larger size or remount new wheels, misfits can cause up to 2,000 x 20 minutes per misfit or approximately 600 hours of lost production for the mounting cell. Considering some heavy haul shops are in extremely remote areas where expensive labor is flown in and flown out, the benefits of reducing misfits can be dramatic. These benefits can extend to reduction in inventory levels of wheel and axles normally stocked to account for lower yields and reduction in floor space utilized.

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