DEVELOPMENT OF A STATION CONTROL SYSTEM FOR AN ENGINE ASSEMBLY LINE

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ABSTRACT

Optimisation of engineering systems is a key task in industry. This paper presents a case study of the optimisation of a production process which was undertaken at General Motors South Africa (GMSA). One of the engine assembly lines was identified as a strong candidate for improvement, particularly in terms of ergonomics, safety and overall operating procedures. The developed solution is in the form of a station control system, utilising automation to enhance the production facilities and improve the identified target issues. The design centres around an intelligent workflow control system, integrating mechanical elements with automation, and subject to industrial safety requirements. Incorporated within this system is a means to divide the line into designated stations, and a pacing system to alert operators as to cycle time progression. The primary aspects, details and results of this industry project are presented and discussed. The project solution achieved the goals of providing manufacturing-related assistance and problem solving for local industry.

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1 INTRODUCTION

In modern manufacturing, especially in light of increased globalisation, a primary goal is to ensure high production efficiency. Optimal productivity is fundamental in ensuring the competitiveness of a firm. While true for all organisations, it is particularly important for manufacturing and related industries. Consequently, assembly and production lines are often evaluated in terms of their suitability for enhancements and the possible implementation of continuous improvement initiatives.

While the minimisation of cost and maximisation of efficiency are typical objectives of any optimisation process [1], there are numerous additional goals and constraints applicable to each unique situation encountered in industry. The aim of this paper is to showcase a specific example of line optimisation encountered within the local automotive industry, through an industrial case study based at General Motors South Africa (GMSA).

For this industry project, emphasis was placed on adhering to a systems engineering approach [2]. Specifically, the optimisation of the engineering system needed to be considered in a holistic sense, encompassing a multi-disciplinary, mechatronic solution and focusing on a structured design process. The paper highlights the key aspects and results of this project within this framework.

2 BACKGROUND

General Motors are one of the major manufacturers in the local automotive industry and have a strong presence in the South African market. GMSA have based their manufacturing operations in the Eastern Cape, with the main Struandale assembly plant located in Port Elizabeth. In 2009, GMSA established a university-industry collaboration with Nelson Mandela Metropolitan University (NMMU), in the form of the GMSA Chair of Mechatronics. The Chair aims to enhance human capital development through research and innovation, with a key strategic objective to provide manufacturing-related assistance and problem solving for the local automotive industry. One such industry project was the development of a station control system for an engine assembly line at GMSA.

For the various engine derivatives of the Chevrolet Utility pickups, the engine assemblies are built up on a separate assembly line that feeds into the main production line. The base engine blocks are loaded onto fixture stands at the start of this line via a hoist system. The required assembly operations occur sequentially at stations along the line, with the engines manually pushed along the roller bed system to the subsequent station. At the end of the line, the completed engine assemblies are transferred to the engine marriage station on the main line via a semi-automated hoist system. The empty fixture stands are returned to the beginning of the engine assembly line on a driven roller bed running below the primary roller bed of the line. Figure 1 illustrates the principal components of the assembly line.

Despite having satisfactory engine assembly operations, this line was identified as a strong candidate for improvement. Two primary issues were identified during the initial evaluation. Firstly, operators working on the engine assembly line had no indication as to the cycle time progression dictated by the main production line. Secondly, the line is a single continuous roller bed with no physically designated stations. The design of the fixture stands, mounting of the engines, and uncontrolled manual transfer of engines along the line allows for collisions between adjacent engine assemblies. The dual concern of an operator safety hazard and the possible damage to vehicle components is thus present. These two issues can be addressed through a pacing system (to alert operators on their progress and how quickly they are required to work) and a station control system (to control work flow on the line).
3 PROBLEM ANALYSIS AND SYSTEM REQUIREMENTS

Based on the evaluation of the engine line, the requirements for the system modifications were divided into two main sections: a pacing system, and a station control system. Although defined separately, these two elements are closely inter-related and are to be integrated in the final design. The aim of these line modifications, as identified in correspondence with GMSA engineering staff, relate to a three-fold optimisation plan:

1. Improvement of work flow on the engine assembly line, and changes to the current operating procedures, in order to optimise productivity and process efficiency.
2. Improvement of quality control on the line, and implementation of error-proofing measures, in order to achieve higher consistency.
3. Improvement of ergonomic and safety factors on the line.

The top-level structure of the system modifications is presented in Figure 2. In following GMSA standards and common industry practise, all automation and intelligent error-proofing on the line is to be controlled via a centralised PLC. In addition, a Human Machine Interface (HMI) was deemed necessary to provide authorised personnel with status information monitoring and control options for the line. As illustrated in Figure 2, the pacing and station control systems each have their own sub-systems.
The pacing system is required to alert operators as to the cycle time progression for each station on the line. This is necessary to ensure that production time along the engine assembly line is standardised and that the possibility of delays in delivering engines to the main line is mitigated. Preliminary analysis of the current procedures indicated a need for a three stage alert system for the line workers to ensure takt times are adhered to. The alerts were determined to be required at 75%, 95% and 100% of the cycle time to indicate the need to speed up operations and/or the presence of production delays.

The station control system is required to employ mechanical elements to divide the line into separate designated stations and control the work flow between these stations. This system should make use of stoppers at various points along the line, with intelligent control of the stoppers and interaction with the pacing system. Engine assemblies must be prevented from moving along the line if the subsequent stations are not ready, as well as when critical tasks (such as torque operations and oil filling) have yet to be performed at the relevant stations. This system optimises and standardises the work to meet the performance metrics specified by GMSA [3].

4 DESIGN SPECIFICATION AND DETAILS

A comprehensive Statement of Requirements (SOR) was developed based on a methodical analysis of the system operation and the requirements for the engine line enhancements. During the initial phases of the design process, several concept designs were developed and evaluated against top level technical performance measures. Subsequently, a final design was developed and specified in consultation with GMSA. Additionally, the design considered GMSA and industry safety standards.

4.1 System design

Initial focus was on concept design and finalisation of the proposed system’s specification and operation. The logical basis for the sequence of steps in the station control system operations was of key importance. The control of the mechanical stoppers involved several factors and required careful planning and control, where the stoppers must prevent the fixture stands on which the engines rest from leaving a station unless certain parameters are met. An operational flow chart for the system was developed. The station control system is put in an initial state following start-up, after which a station is triggered by detection of an engine assembly delivered to the station. A timer is then triggered and is continuously compared to the predefined limits set for the station (at 75%, 95% and 100% of the cycle time). While the engine assembly remains in the station, the system progresses to successive states as the time limits are exceeded and appropriate warnings and alerts are displayed for the operators.

Additionally, all the stations along the line are interlinked. The activation of the mechanical stoppers must be staggered so that transfer of engine assemblies to subsequent stations cannot result in accidental collisions. In this sense, the mechanical stopper for station n would be raised as an engine assembly is sensed in station n+1, and would only be lowered once station n+1 is empty and the operator at station n has indicated that work is complete. The control of the stopper is also linked to error-proof monitoring of oil fill and torque operations at certain stations on the line. Figure 3 shows a conceptual schematic of this proposed system, where the line has been divided into stations by mechanical stoppers and each station has a proximity sensor for detection of the engine fixture stands. The system is controlled via a PLC, with indication of cycle time progression displayed using a stacker light. The emergency stops and HMI display are also indicated. The actual engine line has 10 stations; however, the logic remains consistent for four or more stations.
Although the inclusion of push button confirmation from operators and a separate pacing system display for each station would be preferable, the capital expenditure of this system is fairly significant. Consequently, a control system was also developed for the case where a single pacing system display is used for the engine line and work flow transfer between stations is automated (that is, with no push button confirmation).

Since the lowering of the stopper for station $n$ would be based only on the presence of an engine assembly in the following station, the pacing system was initially to be based off the final station. However, since no collisions can occur after the last station, this station has no stopper and can thus be cleared by the operator before work is completed. Additionally, with staggered transfers between stations to avoid collisions, the timer can be reset early (before the standardised cycle time for the line is complete) and result in perceived delays at stations near the beginning of the line. After further analysis, the trigger was changed to station 1 at the beginning of the line. In this way, timing is initiated as each new engine is loaded onto the line and delays can be determined accurately based on the series configuration of stations on the line. Any stations prior to the delaying station would also be held up, and so the timer reset for the line can also only occur once this station is cleared.

### 4.2 Component design and selection

For the pacing system, LCD and 7-segmented displays were initially considered to display the cycle time progression and any stations holding up the line. For the final design, however, a stacker (or tower) light system was selected. With a three light tower, various combinations of green, yellow and red lights (solid or flashing) can be programmed for the different alerts, together with an audible alarm (horn). Stacker lights are also a common standard used within the factory.

For the station control system, an inductive proximity sensor was deemed the most suitable device for the detection of engine assemblies at a station. These sensors would be placed near the centre of each station below the roller bed to detect the presence of the fixture stands. The mechanical stoppers to control the workflow are required to withstand the forces from collisions with the fixtures under repetitive loading over an extended time frame. Additionally, space constraints exist in the form of operators on the sides of the line and the return roller bed for fixtures below the line. Several options existed for these devices. Based on cost constraints and the availability of existing line-side compressed air
supply, a pneumatic solution was selected. Compact pneumatic stopper cylinders, either directly or indirectly blocking the fixtures, would be subject to direct loading on the shaft and would require a vertical configuration. Three further concepts were developed, mounting pneumatic cylinders below the roller bed to actuate a lever or lifting plate to act as the stopping device. This method helps alleviate the space constraint problem and the force on the stopper acts on pins or guides (and not directly on and perpendicular to the cylinder itself). Figure 4 shows two of these designs, with the right hand concept chosen to be implemented as it is more stable and space saving (with horizontal mounting of the cylinder).

![Figure 4: Mechanical Stopper Designs](image)

### 4.3 Further design analysis

In addition to the principal design, further elements were considered. The final design also includes an HMI to allow authorised personnel to monitor the state of the line, down time and work completed. Outputs from the fluid fill station and torque tools were also used in the PLC code to add error-proofing on the line via an interlock to their respective stoppers on the line. As safety is an overriding priority, additional safety specifications were developed following a risk analysis and risk assessment of the proposed new system. Compliance with electrical standards and warning signage mitigated the identified hazards, particularly through a hard-wired emergency stop system and control reliable safety circuitry with automatic monitoring at the system level.

Detailed design work was conducted on various elements of the system. Included within this scope was the design and simulation of the electro-pneumatic circuits for the pneumatic stoppers and the electrical circuits within the panel. The PLC and HMI coding for the system were also developed from the logic flow diagram using modular code, and tested and debugged at this stage. Finally, the mechanical stopper to be used was tested theoretically, with various components analysed separately under expected loadings. Stress analysis was conducted [4,5], based on a yield stress of 250 MPa for the mild steel used.

Using the principles of impulse and momentum [6], the maximum force exerted on the stopper by the engine fixture stands was determined, as was the force exerted by the cylinder to raise the stopper. For the primary stopper bar, the reaction forces were used to calculate the bending stresses from first principles. The maximum bending stress determined was suitably low. The entire stopper system was then validated using Finite Element Analysis (FEA). As shown in Figure 5, the areas of maximum stress for the stopper occur at regions of stress concentrations; however, these stresses were within design criteria. Stress analyses were also conducted for other critical elements, such as the connecting shaft (of the stopper) and the clevis pin (connecting the cylinder and stopper).
5 IMPLEMENTATION

The engine line modifications are to be installed and commissioned in two phases. In addition, testing of the system was done prior to these tasks through the development of a functional scale model.

5.1 Testing and performance

A model of Chevrolet engine assembly line proposed line enhancements was designed and constructed for performance testing and system validation. The model consists of four stations as the logic and control to extend the line to 10 stations does not vary. Each station contains a proximity sensor and stoppers are present for the first three stations. The construction of the conveyor line represents the roller bed, and representative fixture stands can be manually pushed along the line to trigger the pacing and control systems, as with the actual line. Figure 6 presents the scale model. For the first station, a double-acting pneumatic cylinder with 5/2 way valve was used to actuate a mechanical stopper. For stations 2 and 3, the stoppers were simulated by means of solenoids and LEDs for display. The system electronics and control are fully representative of the actual design. A three-tower stacker light with audible alarm was used for the pacing system indication. The system was controlled via a Siemens S7-1200 PLC, fully installed within a modular enclosure with associated circuitry and wiring. A KTP600 HMI was also added and programmed to fully model the final system design, together with data logging functionality to monitor system delays per station.

The scale model was used to test the system in terms of the identified technical performance measures. The first step of testing was to validate the operation of the station control system. The process was tested through initial start-up and continuous line
operation, and the control of the work flow between stations was found to be satisfactory for all possible scenarios. The second stage of testing verified the operation of the pacing system, operator alerts, and HMI display of system delays. The time delays for different station hold-ups were measured and compared to physically measured data, as well as testing of the data logging capabilities. Maintenance override functionality was also tested and validated. The complete system was found to operate correctly for all tested situations expected to be encountered on the actual line.

5.2 Engine line modifications

The line modifications at GMSA’s Struandale plant are to be implemented in two phases. The first phase of installation was completed over shutdown at the end of 2011, as shown in Figure 7. Owing to capacity and time constraints, this installation focused only on basic, critical aspects of the overall system design. The pacing system was implemented by means of a single stacker light for the line, as tested with the scale model. Control has been implemented using the current engine line PLC and available I/O. The line was divided into designated stations following the installation of non-return mechanical stoppers on the line. However, intelligent flow control between the separate stations has not been realised with the current modifications. Nonetheless, the creation of individual stations and implementation of line pacing has already resulted in improved efficiency and safety. Together with operator training, the system has further aided in the standardisation of work procedures.

The second phase, currently planned for installation during shutdown at the end of 2012, will address the remaining aspects of the design. The full control functionality is scheduled for implementation, including a new panel with a new PLC and HMI. The pacing system is to be expanded to include a pacer light for each station and work complete push buttons for each station, as per the original design. Further, pneumatic stoppers under PLC control are set to be installed for each station, while the non-return stoppers will be relocated to the back of each station to further ensure fully controlled work flow on the line. In addition, key switches are to be provided for a ‘bypass’ mode for each station. These additional enhancements augment the first phase installations and will conclude the optimisation and upgrade of the line identified at GMSA.

Figure 7: Phase 1 of Engine Line Modifications Installation
6 CONCLUSIONS

The optimisation of engineering systems within industrial settings is a key element in achieving and surpassing production and other organisational goals. In this paper, a case study was presented, based within the local automotive industry at General Motors South Africa. The end goal of this project was to raise overall production efficiency through the improvement of ergonomics and safety, standardisation of workflow and operating procedures, and quality assurance for the identified engine assembly line. The means to achieve these aims were through the development and implementation of an intelligent pacing and station control system for the engine line.

The two closely interlinked systems were designed at NMMU in consultation with GMSA. Using a scale model to accurately represent the system to be implemented in the plant, the design was validated. Subsequently, the station control system can be physically installed and commissioned in the factory, and the first phase of installation has been completed. Consequently, it can be concluded that significant gains can be achieved through a structured approach of analysing production lines and applying sound engineering knowledge and design in formulating applicable solutions. Additionally, this case study has also illustrated some of the benefits possible through active university-industry collaborations.

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8 REFERENCES


