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AN APPLICATION OF LEAN CONCEPTS AND SIMULATION FOR DRAINAGE OPERATIONS MAINTENANCE CREWS

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ABSTRACT

The City of Edmonton's Drainage Operations Branch oversees the inspection, maintenance, and repair of the city's drainage network of over an area of 700 km^2 to serve a population of over 600, 000. The maintenance activities consume a large amount of funding and, therefore, are sensitive to any improvement in the maintenance crew's productivity. The study focused on selected drainage maintenance crews. The application of the industrial engineering philosophy of work measurement, lean production theory, and simulation analysis was used to capture current work methods, generate and test alternative methods, and develop new standards. As an example, this paper will focus on the methodology utilized for the Service Line Rodding maintenance crews.

1 INTRODUCTION

The City of Edmonton's Drainage Operations Branch is responsible for the maintenance of sewage pump stations, stormwater management facilities, and the drainage system. The network covers an area of 700.6 km^2 to serve Edmonton's growing population of over 600, 000. An efficiency audit conducted by the Office of the City Auditor (OCA) on selected City of Edmonton drainage operations maintenance activities was completed in 1999. The goal of the 1999 audit was to measure and assess the reasonable of management's efficiency and productivity standards for fieldwork, as well as justifying work crew size and levels of supervision. The audit revealed that most of the crews were appropriately staffed but performed their designated maintenance activities inefficiently. Furthermore, productivity standards have not been formally developed and used in a meaningful manner for day-to-day control of operations and performance measurement. Moreover, the audit discovered that a significant amount of annual budget could potentially be saved by altering some of the crews' work methods as well as developing productivity standards. As of 2000, the replacement value of drainage infrastructure was approximately 49% of the total City of Edmonton infrastructure facilities. Therefore, it is important to possess crews that work efficiently to maintain the drainage systems. This work analysis study involving the City of Edmonton's Drainage Services Branch, the OCA, and the University of Alberta's Construction Engineering and Management Group was conducted to develop improved work methods, productivity standards, a standard for material and equipment costs, and an updated physical demands analysis. This project is one of the initiatives being undertaken in Drainage Services and Drainage Operations to improve the efficiency within the branch to meet the City Council directive for achieving efficiency improvement.

This study focused on the following six activities that account for 25% ($3 million) of the total drainage operations budget: (1) cleaning mains by Low Pressure Flushing (LPF), (2) cleaning mains by High Pressure Flushing (HPF), (3) scheduled mechanical Cleaning of Catch Basins (CBC), (4) inspecting Mains by Televising (MTV), (5) Commercial Establishment Investigation (CEI), and (6) Service Line Rodding (SLR). The study was carried out using industrial engineering techniques and simulation methodologies to improve the crews' performance. The LPF activity was selected as the pilot study to evaluate these methodologies. The research resulted in the development of a productivity standard based on current work methods as well as examining and modifying the work method. Crew productivity, i.e. the number of meters flushed per shift, had increased by 29%, up to 2820 m/day from 2194 m/day. As of November 2002, 3 out of the 5 crews met or exceeded the standard regularly.

This paper focuses on the application of lean theory to the current drainage operations maintenance crews' work methods utilizing simulation analysis. However, to illustrate the proposed methodology, the SLR work method will be investigated.

2 BACKGROUND

The principles of lean-thinking are adapted from lean production philosophy developed by Toyota led by engineer Taichi Ohno (Howell, 1999). The term "lean" was introduced by the research team working on international auto production to reflect both the waste reduction characteristic of Toyota's production system and to contrast it with craft and mass forms of production. Ohno advocated the shift of attention from craft production (worker productivity) and mass production (machine productivity) to the entire production system. The underlying philosophy of lean production theory is the avoidance, elimination, or reduction of waste. Waste is recognized by lean production theory as performance criteria, i.e. failure to meet the unique requirements of a client. In other words, time, space, or material used in the performance of an activity that does not directly contribute value to the finished product. Industrial engineering defines waste as a non-value added work step classified as being handling, transportation, delay, inspection, storage, and rework. A value added work step is classified as either being an operation step or a combined operation and inspection step for which the basic work performed is of value to the customer. The terms lean construction, lean production, work design, methods engineering, methods study, or work simplification can be used interchangeably since the same fundamental principles apply.

Simphony, software developed by the University of Alberta, is an integrated environment for construction simulation. The introduction of Simphony provided the practitioner who is knowledgeable in a given domain, but not necessarily in simulation, the ability to develop a special purpose simulation (SPS) with visual modeling tools that highly resemble the real-world construction system. The services provided by Simphony as a development environment allows for developing flexible and user-friendly simulation tools in a relatively short time (AbouRizk and Mohamed, 2000). Although Simphony's intent was to provide as a medium to develop SPS tools, its strength also lies within its ability to develop general purpose simulation (GPS) tools. Minimal background in simulation, however, is required to exploit Simphony's GPS ability.

The objectives of this research are to develop and implement productivity standards for selected work crews, to determine the impact on productivity upon the development of productivity standards, and the incorporation of lean theory and simulation. This was carried out using the Work Analysis Study (WAS) which involved extensive data collection and analysis of the work crews. Each work activity in drainage operations maintenance was observed for a full shift at a time over a 3-month period and subsequently analyzed to develop productivity standards using spreadsheets. This data was normalized to be used for the GPS models developed by the Construction Engineering and Management (CEM) Group. These models were created in conjunction with the Work Analysis Study involving the City of Edmonton Drainage Operations Branch, the Office of the City Auditor, and CEM Group at the University of Alberta. Several of the current GPS models had to be modified accordingly due to modifications done by the observer during the data collection.

This research used simulation as the means of integrating lean principles to the current work methods of the crews. The challenge is to determine if the development and establishment of productivity standards produced effective gains in productivity and whether or not the application of lean theory provided any productivity improvement for the crews of drainage operations using the GPS models. This paper focuses on describing the results for the SLR maintenance process.

3 CURRENT SERVICE LINE RODDING (SLR) METHOD

The activity is divided into three major tasks: (1) work preparation, (2) SLR work steps, and (3) work completion.

1. *Work Preparation* – At this time, the foreman briefs the 2-person crew on the situation and assigns them a residential address (or addresses) to visit. A thorough vehicle check is performed to ensure that the vehicle is safe and functional to operate and that all equipment and materials necessary to perform the activity are present. After putting on personal protective equipment, the crew travels to the first location.
2. *SLR Work Steps* – Before the crew can contact the customer, adjacent sewer mainlines are inspected to rule out the possibility of having a plugged main as the source of the complaint. Next, the crew greets the customer and asks a series of questions to possibly diagnose the nature of the problem. The cleanout (sewer entry in buildings) is then located and inspected to ensure that the problem is actually within the service line that runs from the house to the mainline sewer. If not, the problem may be an inside plumbing one where the crew is not responsible for. Therefore, they inform the customer of the situation and notify their foreman. The foreman can then assign them another address to visit. Otherwise, if the problem is within the service line, the crew carries on by bringing in the necessary equipment and tools to the workspace. The sewage service line is rodded by the operator using a machine that inserts and rotates a snake-like piece of equipment with an interchangeable cutting end into the line. This action is done until either an obstruction occurs or the mainline has been reached. The blockage should be released at this point. After removal of the snake by both the operator and la-

bourer, a specialized camera is inserted to inspect the line for possible structural defects (collapsed pipe, cracks, misaligned pipe) and physical obstructions (roots, grease, etc.). This is recorded and documented at various distances along the service pipe. The workspace is then cleaned up and their equipment and tools are removed and stored in their truck. The customer is notified of the work done and of any necessary steps to act upon as a result of the problem. After all work has been completed at the location, the foreman is called to assign the crew a new location to repeat the work conducted. Otherwise, the crew returns back to the yard.

3. *Work Completion* – Upon arrival at the yard, the crew cleans, inspects, and stores all equipment used during the shift. All paperwork is then completed and submitted to the foreman.

3.1 Lean Thinking Application

The principles of lean-thinking have been applied. The SLR activity was broken down to a number of tasks and then further subdivided into work elements for the time study. In addition, each element of the work process was designated as either value added (VA) or non-value added work step. Table 1 represents part of the element breakdown for the SLR maintenance activity. Column 3 represents the accumulated amount (time) over the entire shift. For example, for "Power Rodding Service Line", normal time = total raw time/number of observations = 1476/57 = 25.896 minutes. Therefore, the "Process Step Cycle Time" for the step "Power Rodding Service Line" = normal time X frequency = 25.896 X 2.11 = 54.64 minutes. The areas for improvement of the maintenance activity process are identified. That is, the means of reducing the fraction of non-value added tasks to increase the fraction of value-added work steps is investigated. A minimum reasonable ratio between value added and non-value added is 50/50. Ideally at this level (task or work step) an 80/20 ratio should exist to minimize the amount of NVA steps in the entire business process. If the NVA steps are not minimized at the task (or work step) level, 90 to 98 % of the entire business process will end up being non-value added. However, any improvement in the overall productivity of the crew is acceptable and shows progress in the right direction. The breakdown of VA and NVA process steps for the Service Line Rodding crews is 32% and 68% respectively as illustrated in Figure 1. This indicates that the crew is inefficient in its work methods and in the deployment of workers and could have their performance increased significantly through the application of lean concepts, better scheduling, routing, and developed engineered productivity standards. The predominant NVA steps are transportation, handling, and delays, which account for 27%, 14%, and 14% of the total time on the job, respectively. The delay time consists of talking to the foreman on the phone (14%), unrelated work (28%), productive interruption (14%), instruction (5%), personal time (15%), excessive work (19%), and idle time (15%).

Developing suggestions to improve performance of all crews require the input, support, and consultation with training personnel, the crewmembers, management, and Occupational Health & Safety (OH&S). However, most improvement ideas have only been discussed with the Office of the City Auditor and are used solely for the purpose of illustrating the potential gains in productivity subsequent to implementation. In certain instances, there was saturation of the existing work method and hence, only technological advancements was the only possible means

Table 1: Part of SLR Element Breakdown and VA/NVA Identification (Agbulos, 2003)

Element	***Process Step Cycle Time***	***Normal Time (xfrequency)***	***Process Step***	***Symbol***	***VA/NVA***
Work Preparation					
Get Instructions	8.21	7.14 (x1.15)	Operation	●	VA
Vehicle Inspection	8.34	8.97 (x0.93)	Inspection	■	NVA
Work Steps					
Setup Equipment #1 (Rod)	16.85	7.99 (x2.11)	Handling	▶	NVA
Power Rodding Service	54.64	25.90 (x2.11)	Operation	●	VA
Remove Equipment #1	22.61	11.31 (x2.00)	Handling	▶	NVA
Setup Equipment #2 (TV)	10.49	4.30 (x2.44)	Handling	▶	NVA
Feed Camera & Record	29.07	11.35 (x2.56)	Operation	●	VA
Remove Equipment #2	18.94	7.99 (x2.37)	Handling	▶	NVA
Work Completion					
Clean Equipment	21.57	12.12 (x1.78)	Operation	●	VA
Paper Work	41.34	9.96 (x9.96)	Operation	●	VA

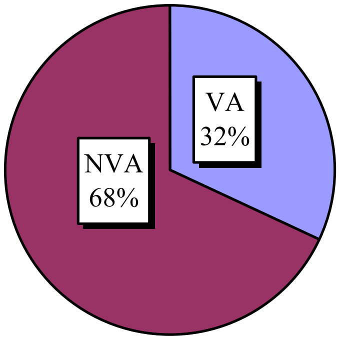

Figure 1: SLR Breakdown of VA vs. NVA Minutes

of improving the cycle time of a process step and therefore improving the productivity of a crew. In most other cases, slight changes to the process combined with technological advancements were the keys to gaining enhancement in the crews' productivities.

3.2 Simulation Application for Current Situation

The current SLR General Purpose Simulation (GPS) model is built in a hierarchy that represents different levels of detail for the activity, which represents a typical workday, but does not include delay time (lost time and productive foreign elements). The highest level of the hierarchy (parent window) as shown in Figure 2 represents the work preparation, work steps, work completion (end-of-day), and transportation elements. The actual service line rodding is found at the lowest level of the hierarchy (child level). The model runs for 100 simulation days to collect statistics on the number of locations (or sites) visited per day. The output of the model revealed that the mean productivity is 3.76 locations per day and ranges from 3 to 5 locations per day.

3.3 Applied Lean-Thinking

Figure 3 represents a few of the suggestions implemented within the simulation model. To simplify the implementation process for SLR, the assumption that the smaller cycle time (5.23 minutes) of "Check Mainline" performed by the labourer occurs within the larger cycle time (8.68 minutes) of "Greet Customer" performed by the serviceman resulted in the formation of a work step that incorporates both elements. Consequently, the non-value added task "Check Mainline" has been eliminated in favour of the value-added "Greet Customer" task to create a "Check Mainline/Greet Customer" value-added element. As well, the smaller cycle time (17.06 minutes) of "Inform Customer/Problem" performed by the serviceman is assumed to occur within the larger cycle time (18.94 minutes) of "Remove Equipment #2" performed by the labourer resulted in the formation of a work step that accounts for both tasks. Again, the non-value added task "Remove Equipment #2" and value-added task "Inform Customer/Problem" combined to create the value-added "Remove Equipment #2/Inform Customer" element.

In terms of introducing an automated labour tracking system, based on observing the crews during the data collection period, an educated guess of a 15-minute cycle time for the element "Paper Work" has been assumed. That is, the current uniform distribution (low – 0.63 minutes, high – 36.7 minutes) has been modified by assuming a smaller "high" value of 15 minutes. After implementing the changes as described, an increase from 3.76 to 4.16 sites per day yields an

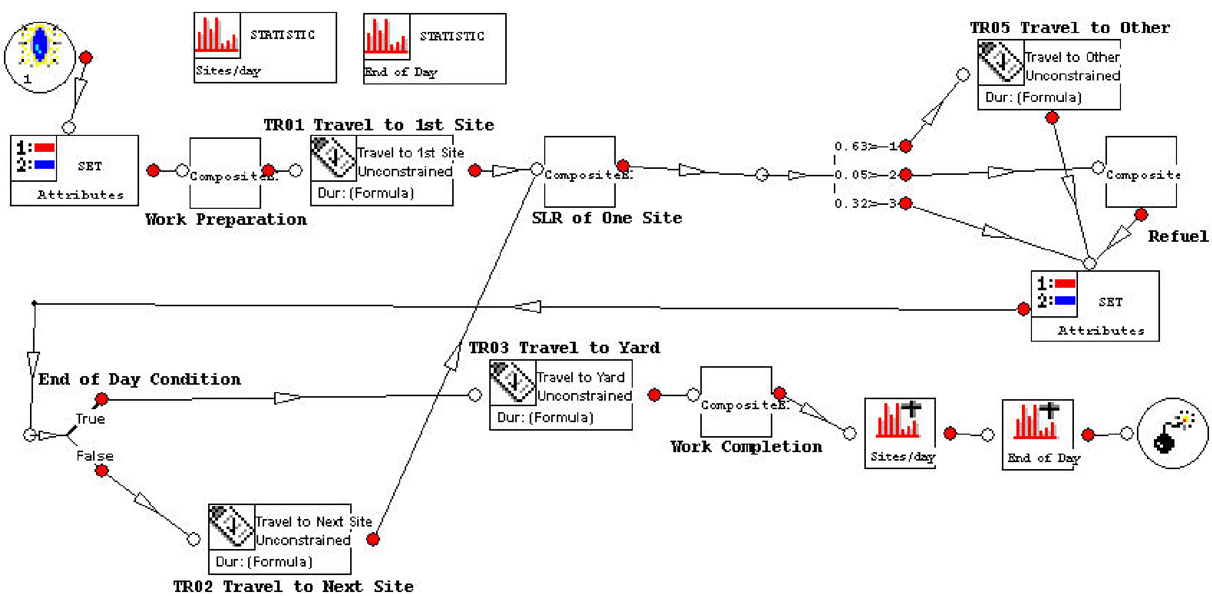

Figure 2: Current SLR Simulation Model Parent Window (Agbulos, 2003)

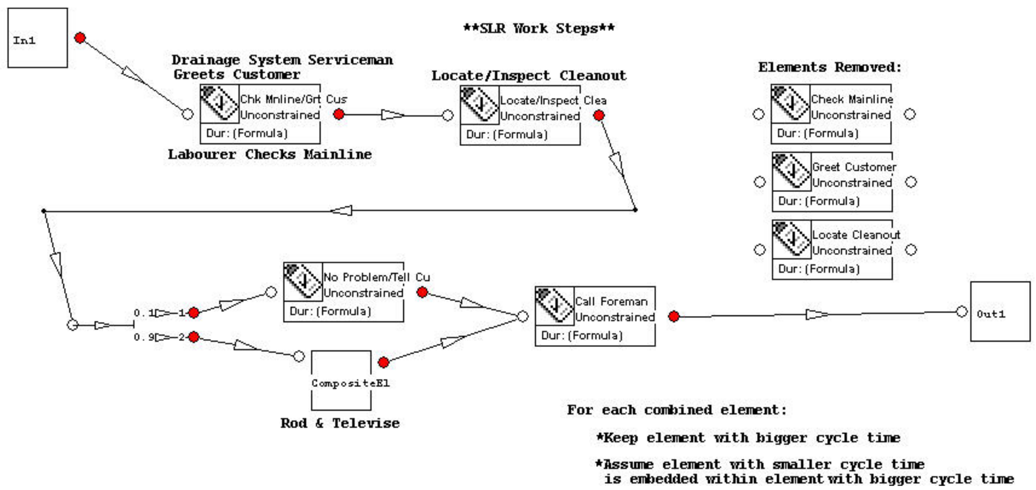

Figure 3: Modified SLR Child Window of "SLR of One Site" (Agbulos, 2003)

increase of 0.4 sites per day or 10.6 %. This proves that an enhancement of productivity in the simulation model by lean thinking is possible. In addition, Figure 4 displays the difference in productivity gained before and after lean application. For instance, at a probability of 80%, the productivity is higher for the modified work method than the current work method.

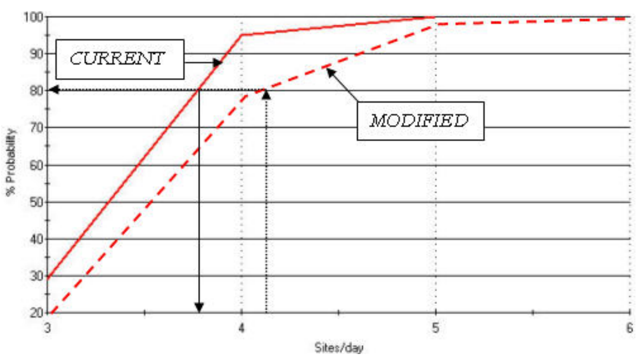

Figure 4: Cumulative Distribution Functions of Current and Modified SLR (Agbulos et al., 2003)

4 SUMMARY OF RESULTS

The remaining crews undergo the same process as described by the mainline televising example. By applying lean-thinking concepts to the general purpose simulation models developed by the University of Alberta for the remaining work crews, the results can be summarized in Table 2. The "Historic Daily Throughput" was calculated based on an accumulated average during a 5-year period (1995 to 2000). The "Work Measurement" data is the current daily accomplishments based on a 90% confidence level and 5% precision. The "Potential % Change" is the percentage increase in productivity of the work crews. As it can be seen, CEI and SLR demonstrated the greatest productivity gain, and therefore, these would have the highest priority over the rest of the crews in terms of implementation and investigation by management, training personnel, and Occupational Health & Safety (OH & S). In addition, a cost-benefit analysis as well as organization-wide commitment and co-operation by all parties involved would be required prior to any implementation.

5 LIMITATIONS AND CONCLUSIONS

The reality of simulation is that every scenario possible can not be accounted for. As a result, the models were developed using probability branches. Each of those branches attached to an element (or work step) was assigned a probability unless the element was assumed to occur during every cycle. That is, the chance of an activity occurring was either assumed to take place after every cycle (entire shift) of the actual maintenance work (such as mainline televising) or an element out-of-sequence that could occur at any moment (e.g. delays such as unrelated work, excessive work, idle time, personal time, productive interruption, and instruction) was assigned a probability value (percent). The models were set up in a way that work flowed as continuous as possible. In addition, some instances of the application of lean concepts to current drainage operations maintenance crews relied on assumptions. These assumptions had to be made due to either poor quality data or the data not collected at all. Having had several different analysts may have had an effect on gathering consistent results. An assumed reduction, based on judgement from observing these crews, in a work element's cycle time occurred whenever an introduction to a new technology or tool (automated labour tracking method, more versatile mainline camera, tool belt, etc.) had been suggested. Having such technologies in place may increase the accuracy of the reduction in the task's cycle time. The paper illustrated the improvement in SLR productivity of 10.6% that can be attained by applying lean theory to current SLR work methods. Though the results are successful, i.e. improve-

Table 2: Summary of Results After Applied Lean-Thinking to Simulation Models (Agbulos et al., 2003)

PRODUCTIVITY EFFECTS SUMMARY					
CREW	*Historic Daily Throughput*	*Work Measurement*	*SIMULATION RESULTS*		
			Current Methods	*Improved Methods*	*Potential % Change*
CEI	6.68 sites/day	13.18 sites/day	13.93 sites/day	16.24 sites/day	+ 16.6 %
SLR	3.66 sites/day	3.99 sites/day	3.76 sites/day	4.16 sites/day	+ 10.6 %
CBC	43.49 sites/day	40.17 sites/day	42.52 sites/day	44.25 sites/day	+ 4.00 %
HPF	525.38 m/day	523.39 m/day	580.73 m/day	607.96 m/day	+ 4.69 %
MTV	345.87 m/day	360.53 m/day	366.35 m/day	382.08 m/day	+ 4.29 %

ments in productivity have been demonstrated by applying lean concepts and utilizing simulation as the means to achieve this, the extent of the benefits of such a study can only be experienced by implementation. Finally, all suggestions must undergo consultation and gain support from Drainage Operations management, training personnel, and OH & S.

The detailed investigation and description of the framework for integrating lean theory and simulation methodology provides the tools necessary to improve labour productivity for drainage operations maintenance activities. Although current time study methods are effective, the main advantage of the software selected for data collection is its low cost, simplicity, versatility, and short data processing period. Combining that with Ohno's lean mindset and using simulation to carry out those alternatives resulting from lean thinking, the idea of being able to apply the methodology outlined in this paper to any repetitive work process in any industry is very promising.

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