A Productivity Model for Performance Evaluation of the UT Automated Road Maintenance Machine

Kim, Young-Suk[1], Ph.D. Candidate
Husbands, Jason K., Graduate Research Assistant
Haas, C. T., Associate Professor, Ph.D., P.E.
Greer, Richard, Research Scientist
Reagan, Angela, Undergraduate Research Assistant

Department of Civil Engineering
University of Texas at Austin
Austin, Texas 78712, USA

Abstract

An Automated Road Maintenance Machine (ARMM) for automatically sealing pavement cracks has been developed by the University of Texas at Austin. Automating pavement crack sealing can improve safety, productivity and quality and reduce road user costs as well. Recent initial field trials of the full scale crack sealer have indicated that automated pavement crack sealing is now technically, economically, and financially feasible. This paper describes the methodology for determining the productivity of the ARMM to evaluate its performance. The main objective of the productivity study is to examine if the ARMM can meet the productivity of a standard crack sealing crew. To predict the productivity of the ARMM under different field conditions, a mathematical model is developed and presented in this paper. Data for the productivity analysis will be collected from a series of field trials being conducted at the UT research campus and to be completed at five districts in the state of Texas.

1: Introduction

In recent years, several systems for automatically routing and sealing pavement surface cracks have been developed. Examples include (1) the CMU-UT Field Prototype (1992), (2) the Cal-Davis Field Prototype (1993), and (3) the UT Automated Road Maintenance Machine (ARMM) (1996). Through trial and error and over 8 years of perseverance, the UT ARMM has achieved an optimal balance between human and machine functions for automated pavement crack sealing[3]. For automation of pavement crack sealing, complete autonomy can be achieved, but at a cost and speed that is unacceptable[2]. This was apparent with the first CMU-UT field prototype, which used laser range sensing and machine vision to autonomously identify and map cracks.

Currently, the ARMM combines machine vision and operator identification of the cracks to be sealed in order to map their exact locations in the machine's workspace. Recent field trials of the full scale crack sealer have indicated that automated pavement crack sealing is now technically, economically, and financially feasible. However, there is a need for periodic productivity studies of the full scale crack sealer to evaluate its performance as it is further refined.

First, this paper briefly describes five specific functions for teleoperation of the ARMM. Then the paper will mainly focus on describing the methodology for determining the productivity of the ARMM. A mathematical model for measuring the system productivity has been developed based on the different types (longitudinal, trans-

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[1] Correspond to youngsuk@mail.utexas.edu or (512) 471-4648

verse, and blocking) of cracking in a road section. The productivity of the system is measured via time studies of the operating tasks individually and via aggregate time trials over full road sections. Data for the productivity analysis will be collected from a series of field trials to be completed at five districts in the state of Texas from March to May of 1997. The productivity analysis will be performed based on five major components of operating tasks representing one work cycle of the automated crack sealing machine (Figure 4).

The objectives of the paper are: (1) to develop a mathematical model for predicting the productivity of the ARMM under different field conditions, and (2) to quantify the productivity of the ARMM. Figure 1 shows the physical system configuration of the ARMM.

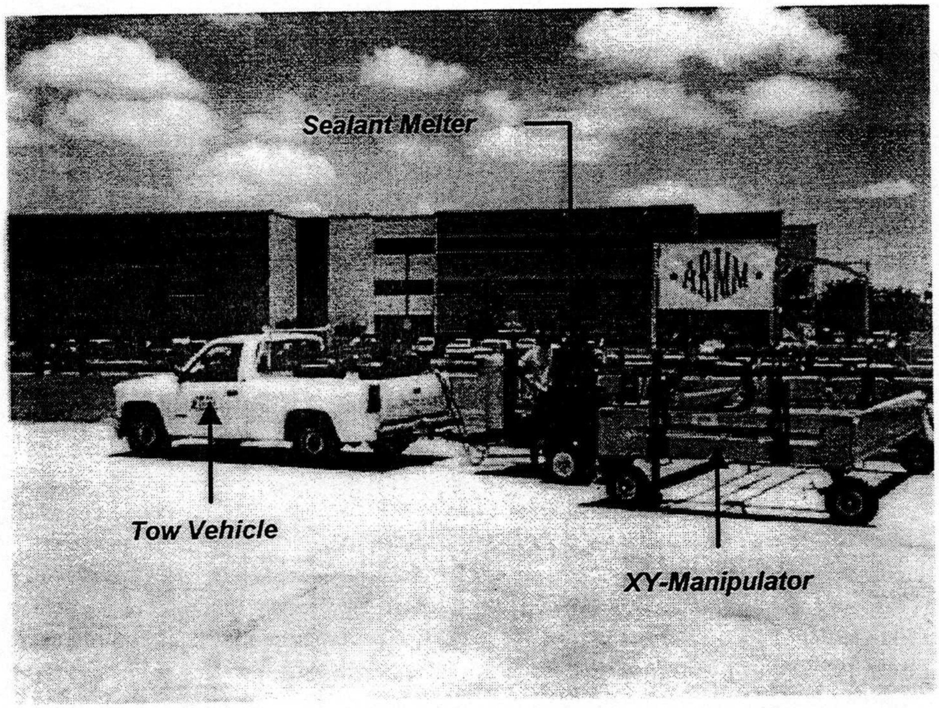


Figure 1. Physical System Configuration of the ARMM

2: Automated crack sealing process

A complex evolution over several years has resulted in a functional production prototype system that has achieved a good balance between manual and automated functions. Many tools and algorithms were also developed to implement the prototype [1,2,3]. Such a man-machine balanced crack sealing process to control the ARMM is illustrated in an extremely simplified form in this paper.

To control the ARMM through a work cycle, several steps are required: (1) image acquisition, (2) crack mapping and representation, (3) line snapping and manual editing, (4) path planning, (5) manipulator and end effector control, and (6) travel to next work space (Figure 2). First, a computer imaging system is used to view cracks on the roadway. The system operator (who also drives the tow vehicle) identifies crack locations by drawing graphical lines over the cracks on a video screen using a touch sensitive stylus (Figure 3a). Under proper conditions of illumination, humans can easily distinguish real cracks from pavement background noise such as sealed cracks or oil or skid marks. An abstract graphical representation of the crack network to be sealed provides visual feedback to the operator. Machine vision based line snapping (Figure 3b) and occasional manual editing (Figure 3c) are also required to compensate for the errors caused by imperfect human hand-eye coordination. Results from initial field trials indicate very accurate adjustment using line snapping. The resulting graphical representation is directly used for automated path planning[3] and optimization for the ARMM.

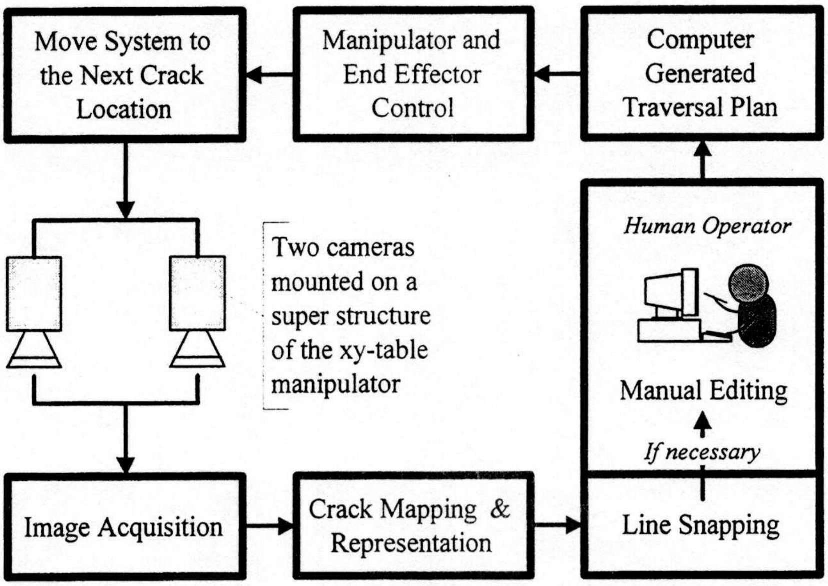
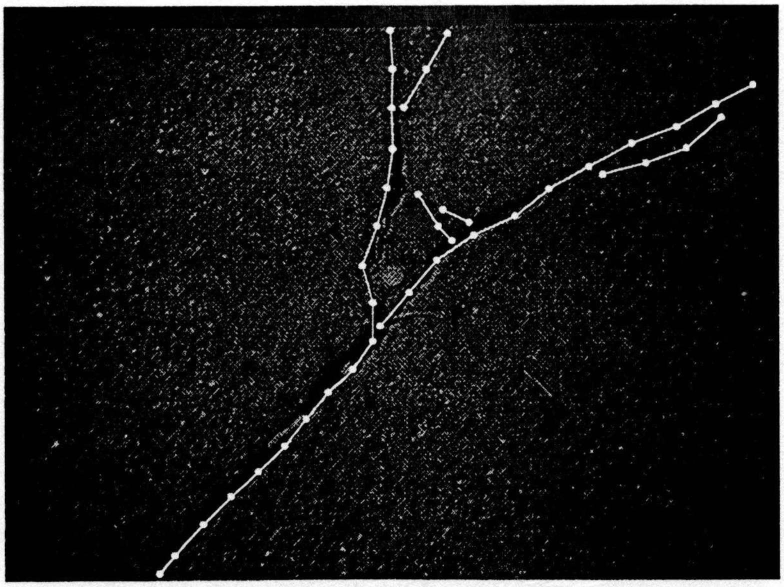
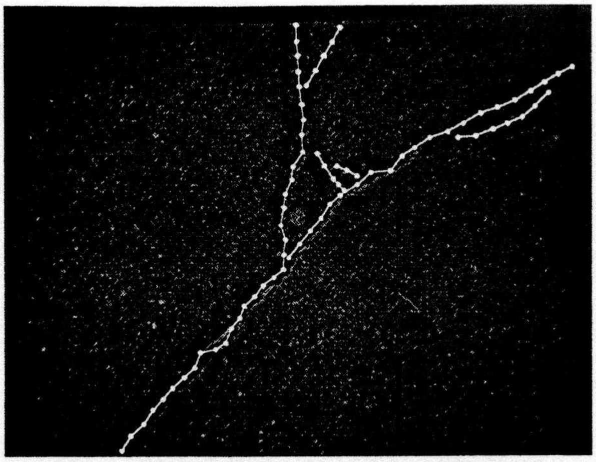


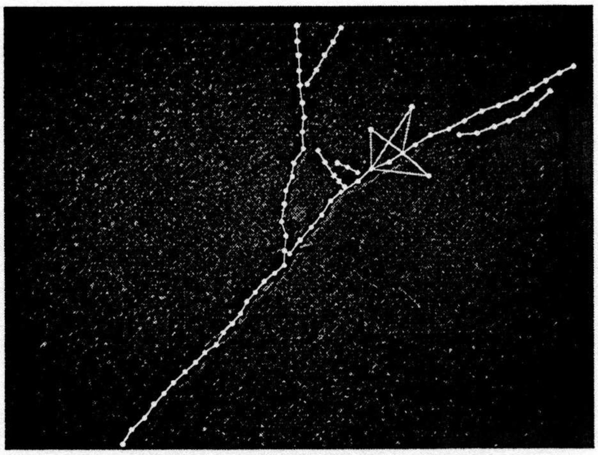
Figure 2. Machine Vision Assisted, Tele-Operated Crack Sealing Process



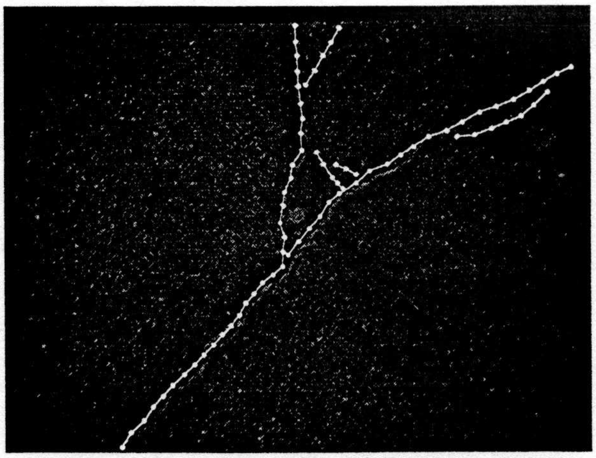
(a) Crack Mapping and Representation



(b) Line Snapping



(c) Manual Editing

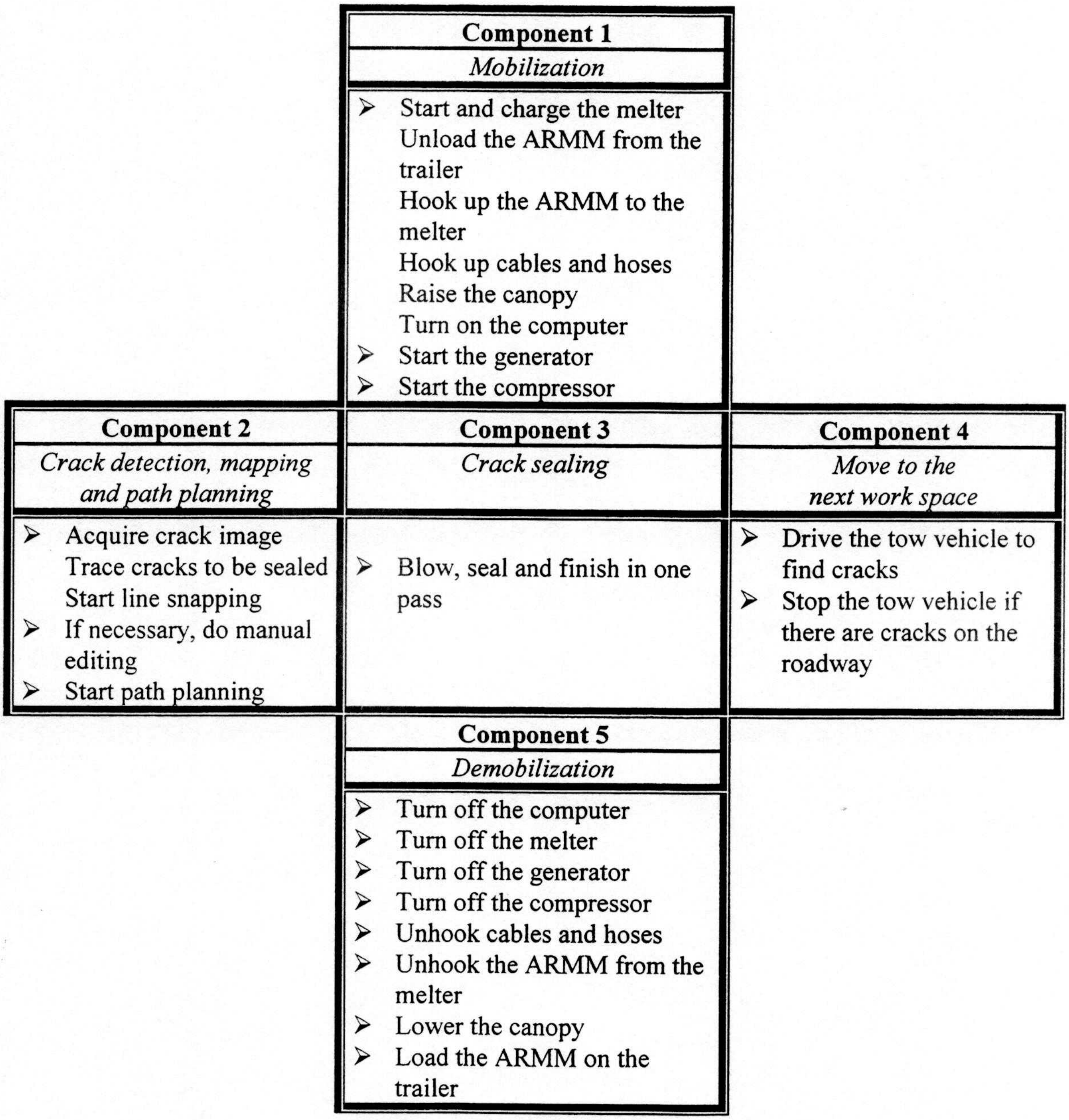


(d) Crack Representation for Path Plan

Figure 3. Graphical Control for Automated Pavement Crack Sealing

The ARMM uses an xy-manipulator with a rotating turret to blow, seal, and squeegee cracks in one pass, thus greatly improving productivity of the system. While the manipulator is moving within its workspace, its frame is stationary. Sealing Cracks in one workspace and then moving to the next workspace is considered one work cycle.

When compared to conventional crack sealing operations, duration of accurate crack detection and mapping (manual crack mapping, line snapping and manual editing), efficient movement of the crack sealer (path planning) and manipulator speed would be key factors in its performance. Other performance factors include time taken for mobilization and demobilization, and transition of the workspace. Figure 4 describes the work cycle of the ARMM. A Productivity study of the ARMM is performed based on the work components classified in that Figure.



Component 1
Mobilization

➢ Start and charge the melter
Unload the ARMM from the trailer
Hook up the ARMM to the melter
Hook up cables and hoses
Raise the canopy
Turn on the computer
➢ Start the generator
➢ Start the compressor

Component 2
Crack detection, mapping and path planning

➢ Acquire crack image
Trace cracks to be sealed
Start line snapping
➢ If necessary, do manual editing
➢ Start path planning

Component 3
Crack sealing

➢ Blow, seal and finish in one pass

Component 4
Move to the next work space

➢ Drive the tow vehicle to find cracks
➢ Stop the tow vehicle if there are cracks on the roadway

Component 5
Demobilization

➢ Turn off the computer
➢ Turn off the melter
➢ Turn off the generator
➢ Turn off the compressor
➢ Unhook cables and hoses
➢ Unhook the ARMM from the melter
➢ Lower the canopy
➢ Load the ARMM on the trailer

Figure 4. Five Components Classified for Productivity Study of the ARMM

3: Methodology

The mathematical model which predicts the productivity of the ARMM was developed as a means of rating the performance of the ARMM. The first assumption made when developing this model was that the current prototype of the ARMM would only seal longitudinal, transverse, and block cracking. Transverse cracking consists of cracks or breaks which travel at right angles to the pavement centerline. Longitudinal cracking consists of cracks or breaks which run approximately parallel to the pavement centerline. Block cracking consists of interconnecting cracks that divide the pavement surface into approximately rectangular pieces, varying in size from 1 foot to 1 foot up to 10 feet by 10 feet.

The most difficult part of the development process was determining how to quantify the distress of the pavement section to be sealed. Previous analysis showed that degree of the pavement distress was the dominant factor affecting the productivity[4]. The more distressed a pavement section, the longer it would take to seal that pavement section.

To rate the overall performance of the ARMM, the tasks associated with its operation were divided into five major components. These sections were then itemized and individual sub-tasks were identified. These sub-tasks were then isolated and evaluated separately. The evaluation results of each sub-task were finally added together to determine the overall productivity of the system. Figure 4 shows the major tasks and sub-tasks associated with the operation of the ARMM

The general productivity model developed incorporates three of the five major components. These components include the time required to: (1) trace the crack image, and perform the line snapping, manual editing and path planning (T*comp2*), (2) blow, seal, and squeegee the workspace (T*comp3*), (3) move to the next workspace (T*comp4*).

The values of these three components will vary according to the severity and type of cracking present on a section of road. The value of the moving component will vary according to the distance between the workspaces, and the travel speed of the ARMM. The first and fifth components of the process are the time (T*comp1*) required to set up the ARMM at the beginning of the work day, and the time (T*comp5*) required to break down the ARMM at the end of the work day, respectively. These components are constant and are added to the final result of the determined productivity. These times do not vary according to the type of cracking on a given section of road, and therefore the values do not have to be constantly evaluated in the model.

4: Crack tracing, line snapping and path planning

The time required for the operator to trace the crack images will be determined through a series of tests. A series of images of pavement cracks, to be collected from field trials, will be used to find the average time it would take for an operator to complete the tracing function. For the next factors (line snapping and path planning) in this component, the computer will be used for accuracy. Monitoring functions will be incorporated into the software which will track of the time required to line snap a given image, and then plan the path for the manipulator to take for that image. Using the software to record these times is much more accurate than timing the functions by other means (i.e. a stopwatch). Initial field trials showed that the line snapping algorithm was very effective thus reducing the need to manually edit crack images. Therefore, the manual editing factor was not considered in this model. Individual values will be recorded for transverse, longitudinal, and block cracking. The values reflect the time to trace (t_t), line snap (t_l), and path plan (t_p) a given linear meters of cracking.

- [Trace time/workspace] * [Number of workspaces] = Total trace time (t_t)
- [(Snap + path plan time)/workspace] * [Number of workspaces] = Total snap and path plan time ($t_l + t_p$)
- T*comp2* = [Total trace time + Total snap and path plan time] = $t_t + t_l + t_p$

5: Crack blowing, sealing, and squeegeeing

This component of the productivity model accounts only for the time required to blow, seal, and squeegee all of the cracks in a workspace after the workspace is in position and the tracing, line snapping, and path planning are completed.

Since the turret assembly on the ARMM moves at constant velocity, the time required to blow, seal, and squeegee cracks is easily determined by dividing the linear meters of cracking on a given pavement section by the velocity of the ARMM's end effector. The total linear feet of cracking on a section of road will be estimated using the methods in the Pavement Management Information System (PIMS) Rater's Manual[5] provided by the Texas Department of Transportation (TxDOT). This rating system was chosen to be implemented into the ARMM's productivity model on the basis that it is an established and proven rating system that is currently being used by TxDOT. Also, the ARMM will be turned over to TxDOT upon completion of the project. Since it is based on TxDOT's system, the productivity rating system will be very easy for PIMS personnel to use because of their familiarity with their current system.

In the cases where there are multiple cracks in a single workspace, the turret assembly takes time to move from crack to crack. The sections of the path between cracks where no sealing is being performed is referred to as idle length. The time taken for the turret to traverse the idle length must be accounted for in the productivity. This time is referred to as idle time. The idle time will be added to the time required to seal actual cracks to determine the total time spent traversing the entire workspace.

- T*comp3* = [Total actual crack length + Total idle length]/[Average velocity of manipulator (30cm. /second)] = Total blow, seal, squeegee time

6: Time due to travel

This component includes the activities involved with advancing the ARMM to the following workspace or series of workspaces. The ARMM will be timed to find the maximum speed at which it can be towed. The time lost due to acceleration will also be determined. With the length of the pavement section known, the required travel distance can be divided by the maximum travel speed of the ARMM to determine the time to move that section. The time lost due to acceleration is also included in the equation.

- T*comp4* = [Required travel distance/Velocity] + [Time loss due to acceleration]= Total time to move

7: Productivity Model

The complete productivity model for the ARMM incorporates all of the components detailed in Figure 4. For the purpose of comparing to previous studies on the productivity of conventional crack sealing methods, the productivity of the ARMM will be determined in units of lane-kilometers per hour. Thus the total equation is as follows:

- Length sealed pavement/[Time to mobilize + (t_t + t_l +t_p) + T*comp3* + T*comp4* + Time to demobilize] = [T*comp1* + T*comp2* + T*comp3* + T*comp4* + T*comp5*] = Total ARMM productivity (lane-km. /hour)

8: Conclusions

Preliminary testing of The University of Texas' Automated Road Maintenance Machine shows that the process is a feasible alternative to the manual crack sealing process. The system has evolved to be an effective tool for pavement maintenance. To measure the actual productivity of the system, a mathematical model was developed. The entire process was divided into its operational components, each of which were itemized further into their respective sub-tasks. The framework for the productivity model was based on these sub-tasks. The tasks were individually analyzed to create a complete and comprehensive model that represents the productivity associated with the operation of the ARMM. Data collected from future field trials will be used to test the effectiveness of the productivity model and identify areas where the productivity of the operation can be improved.

References

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