ABSTRACT

With ever shrinking track time and allowable work windows, increased productivity and quality of track maintenance are more paramount now than ever. Working within conventional North American production tamping practices, HARSCO Rail has developed and implemented “The Drone”, an unmanned chase tamper programmed to tamp ties skipped by the lead tamping machine, in a manner similar to the current manned chase tamper used in conventional and high speed tamping operations.

The Drone tamps all of the ties skipped by the lead manned tamper, while it continuously moves independently of the lead tamper. The work heads on the Drone are automatically and individually positioned to the required longitudinal location on the frame to facilitate tamping the untamped ties; even skewed ties.

The Drone allows for increased tamping production, a reduction in number of operators (and associated risk of lost time injuries) and an overall economic benefit to the railway. The Drone has been implemented on a major Class 1 railroad with great success. The benefits of The Drone include increased tamping productivity, reduction in personnel required, increased safety and associated economic savings.
INTRODUCTION

With ever shrinking track time and allowable work windows, increased productivity and quality of track maintenance are more paramount now than ever. Working within conventional North American production tamping practices, HARSCO Rail has developed and implemented “The Drone”, an unmanned chase tamper programmed to tamp ties skipped by the lead tamping machine, in a manner similar to the current manned chase tamper used in conventional and high speed tamping operations. The design of the Drone is such as to match (and in many cases exceed) current tamping gang productivity but with reduced manpower requirements and reduced overall costs. The benefits of The Drone include increased tamping productivity, reduction in personnel required, increased safety and associated economic savings.

The Drone tamps all of the ties skipped by the lead manned tamper, while it continuously moves independently of the lead tamper. The work heads on the Drone are automatically and individually positioned to the required longitudinal location on the frame to facilitate tamping the untamped ties; even skewed ties. All the accessories on the Drone can be manipulated from the lead Machine (when required) via a two-way wireless Ethernet communication system.

For travel to and from the work site and stabling, the lead tamper and Drone remain coupled together and behave as a single machine. When the lead machine is ready to commence work, the machine pair is switched into work mode, with the physical coupling and brakes disconnected simultaneously. The drone remains stationary while
the lead machine commences working until the safe separation distance (railroad defined) between the machines is reached, at which point it commences tamping operations. During operations, if the distance between the Drone and lead tampers is reduced and reaches a second specified minimum separation limit, forward operation of the Drone is stopped and remains stopped until the working safe separation limit is again reached. The Drone automatically tamps each tie skipped by the lead machine. Through continuous communication and data verification, the two machines remain precisely synchronized in terms of location, regardless of how many miles are traversed during the work session.

The Drone allows for increased tamping production, a reduction in number of operators (and associated risk of lost time injuries) and an overall economic benefit to the railway. The Drone has been implemented on a major Class 1 railroad with great success. The following paper discusses The Drone, its implementation and associated challenges, case studies to date, and benefits, as well as expected economic return.

**DEVELOPMENT OF THE DRONE**

The Drone was developed as an unmanned chase tamper to be used in skip tamping operations with a manned lead tamper. The fundamental philosophy behind this process is to match current conventional chase tamping gangs but with higher production, accuracy, safety, and reduced overall cost. In many cases, two manned chased tampers can be replaced by one Drone tamper.
The basic technology is wireless communication between the lead tamper and the Drone. The various components and salient features are discussed below.

**System Components – Lead Tamper**

When a tamping machine is configured to operate with a Drone tamper, its control system is effectively left unchanged. There are no changes to the operator interface of the lead machine or its operation. To provide for the necessary control of, and interfacing to, the Drone on the lead tamper, a touch screen and Jambox (control computer, identical to the lead machine’s computer) is added. Known as the interface Jam (Jupiter Application Master), all Drone controls and diagnostics are accessed by the lead machine operator through this touch screen.
Through a direct Ethernet network connection between the lead Jam and Drone interface Jam, the interface Jam can access the necessary information needed for operation of the Drone tamper. This information includes encoder location, tie location from the lead’s AutoMag system and various operational modes and actions of the lead tamper.

To complete the composite system, an Ethernet radio provides wireless network communication to the Jambox on the Drone enabling all three Jams to be networked together.

**System Components – Drone Tamper**

The control system on the Drone tamper is a Jupiter control network, touch screen and Jambox combination. Added to this is an Ethernet radio to provide a wireless network connection to the lead tamper, and an independent radio to provide a connection to the wireless hand held remote control device.

The touch screen on the Drone is inside the main junction box and the controls and interface are almost identical to those available on the touch screen of the interface Jam on the lead tamper.

**Operator Control**

While the Drone may give the appearance of being a machine without an operator, in fact, the operator is wirelessly connected to the Drone. The Drone will not initiate, or continue any operation without a direct and continuous link to an operator.
The Drone will receive commands either from the operator on the lead tamper or an operator using the hand held wireless remote. If there is no communication with either the lead tamper or the hand held remote, any operation in progress will be interrupted and the Drone will enter a \textit{work-idle} state. While the hand held remote is turned on, the Drone will only respond to commands from this device. When the hand held device is turned off, control will revert to the lead tamper operator (unless communication is no longer available).

\textbf{Drone Operation}

When commanded to work, the Drone will only move in the forward direction. The Drone will never attempt to move in the reverse direction with the single exception of a reverse motion command that can only be sent from the hand held wireless remote.

The operator on the lead tamper cannot give the Drone a command to move in any direction. Working limits are set by the lead operator. The lead operator can enable work (in accordance with working limits) or disable work only.

If the Drone is not going to tamp a tie in the initial 10 feet, a “fast approach” mode will be entered, with forward speed of 150 feet per minute (about 1.7 mph). The machine will slow down when either nearing a tie to be tamped or the minimum separation distance.
If the Drone is going to skip more than two ties, the work heads will be raised to a clearance height above the top of the rail. If there is no tie to be tamped within 10 feet, the “fast approach” mode is reentered until the next tie is reached. In this manner, minimum time is lost if there is significant distance between ties to be tamped.

**Drone Safety and Maintenance for Safe Intervals between Tampers**

The design of the Drone focused on safety to include audible alarms and automated braking/stopping features.

Air horn signals are used to identify forward motion, and reverse motion. The consistent and predictable behavior of the Drone at all times is an important aspect of safety. No motion is initiated without ample warning of what is about to occur.

While moving forward after initiating or resuming work, the Drone will continuously monitor the forward facing radar units. Any indication that there may be an object within the maximum range of the units (20 feet) will result in short repeated blasts on the forward facing air horns. These blasts will become more rapid for closer distances. Any indication of an object less than half the range of the radar units will result in the Drone abruptly stopping and entering the *work-idle* state. Work will not resume until this condition is cleared.

The radar zone ahead of the Drone is shaped so that trackside obstacles clear of the Drone’s path are not detected.
NORMAL SEQUENCES OF OPERATION

In order to understand how the process works, the following section describes the normal sequences of operation.

**Travelling**

When leaving the stabling location to travel, the lead machine and Drone pair will typically already be coupled. Travelling to the work site is as defined in the following sequence.

1. The lead machine is placed in travel mode.

2. The Drone is placed in travel mode from the operator interface within the lead machine.

The lead tamper is then operated normally for travelling to the work site. The Drone will propel and coast in unison. When necessary, the Drone will shift gears and change engine speed automatically.
Beginning Work

When ready to switch from travel to work mode, a location is selected where the probes on the lead machine are behind the location the lead machine is to begin tamping.

1. The lead machine is switched from travel mode into work mode. At this point, the Drone will also automatically switch into work mode and synchronize encoder locations.

2. The Drone air system is isolated using the manual valve adjacent to the tow-bar.

3. The electrical connection and three quick disconnect brake lines are then uncoupled.

4. The manual valve to retract the tow-bar pin on the Drone is operated.
5. The hand held wireless remote is used, if necessary, to move the Drone slightly to ensure the tow-bar pin has been disengaged.

6. The AutoMag (automatic tie finding system) system on the lead tamper is switched on.

7. The lead tamper is moved forward until the first tie to be tamped by the lead machine has been reached. Tamping then begins.
Drone Work – Lead Machine Operator

Normal operation for the Drone is under the command of the lead machine operator (or Automatic Mode). In this mode, the Drone will initiate work only when work is enabled as follows:

- If the machine separation falls to or below the minimum work limit, (or work-enable is turned off), the Drone will enter work-idle.

- If the machine separation reaches the upper work limit in work-idle and work is enabled, the Drone will resume work.

- If working and skipping more than two ties, the Drone will raise the work heads until they are clear of the top of the tie.

- If working and the next tie for the Drone to tamp is more than 10 feet away, the “fast approach” mode will be used.
Finishing Work

- After the lead machine tamps the last tie to be tamped, the lead machine is moved forward until there is enough clearance behind the machine for the Drone to complete its designated work, without approaching closer than the minimum work separation distance. At this point, the lead machine should be on tangent track to facilitate preparing the lead for travel.

- After tamping the last tie, the Drone will move forward until the minimum work distance is achieved.
The hand held wireless remote is used to move the Drone forward and couple the tow-bar.

The three brake lines and electrical connection on the tow-bar are then connected.

The manual valve that isolates the Drone air system so that it is no longer isolated is opened.

The machine pair is then operated as described above in Travelling.

**ECONOMIC BENEFITS**

In order to understand the economic benefits of the drone tamper operating as part of a conventional production tamping operation, an economic benefit analysis was performed.

The analysis examined using a drone tamper in lieu of a chase tamper in both a High Production Tie and Surfacing (T&S) Gang and as part of a conventional T&S gang.

Table 1 lists the cases that were examined.
<table>
<thead>
<tr>
<th>Surfacing units</th>
<th>Excluding Ballast and switch tampers</th>
<th>Mark VI</th>
<th>Drone</th>
<th>Mark II</th>
<th>Total Equipment</th>
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<tr>
<td>High production T&amp;S Surfacing Unit-</td>
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<td>0</td>
<td>3</td>
<td>4</td>
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<tr>
<td>conventional</td>
<td>number of operators</td>
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<td>Conventional T&amp;S Surfacing Unit-</td>
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<td>conventional</td>
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</table>

As can be seen from Table 1, in the case of a High Production T&S Surfacing Unit, the Drone is able to replace two chase tampers and two operators. In the case of a conventional T&S Gang Surfacing unit, the Drone is able to replace one chase tamper and one operator.

In both cases, the analysis looked at the relative costs and productivity of the two sets of gangs as defined in Table 1.

The most significant benefit is increased productivity with one less machine and two less operators for the High productivity T&S gang’s surfacing unit. Other potential benefits include increased track quality, reduced lost time injuries (due to one or two less men on
the railroad with a potential for injury), and other benefits that have a lesser impact on the economic benefits.

The specific savings analyzed as part of this benefit analysis included:

- **Savings in Annual Operating Costs:**
  - Reduced labor (2 persons)
  - Reduced equipment (1 chase tamper)
- Reduction in Track Occupancy Time due to shorter close out window
- Savings due to reduced lost time injuries.

Thus for the case of the High Productivity T&S Gang Surfacing Unit, working approximately 600 miles per year, the use of the Drone Tamper resulted in savings of approximately $650,000 a year based on an increased productivity of 13.5 ties per minute for the Drone, from the base rate of 13 ties per minute for the High Productivity T&S Gang. In the case of the Conventional T&S Gang Surfacing Unit, the increased productivity of the Drone Unit (576 miles per year versus 532 miles per year) together with the other benefits noted above resulted in a savings of the order of $760,000 a year.

Figures 1 and 2 show the sensitivity of these savings to the actual production rates of the Drone versus a conventional manned chase tamping unit.
Figure 1. Savings using Drone in a conventional T&S gang as a function of productivity.

Figure 2. Savings using Drone in a high production T&S gang as a function of productivity.
As can be seen from these figures, as productivity with the drone increases, so do the economic benefits. More importantly, as the differential in productivity between the two surfacing gangs (Drone versus manned chase tamper gangs) widens, the economic benefits increase. Thus, for example, if there is a one tie per minute improvement by using the Drone, the result is an annual savings of nearly one million dollars. Actual increases in production have shown to be at least one additional tie per minute for one Class 1 railway.

CONCLUSIONS

The implementation of remotely operated work equipment offers significant advantages in production, safety and associated economics. The theory of unmanned work equipment has been put into practice with the development and implementation of the Drone tamper. The machine is currently tamping around 10,000 ties per day, perfectly centering the tamping tools in the possible tamping window at every tie.

Unevenly spaced ties, skewed ties and grade make no difference to this machine. In slippery conditions and rain, the Drone maintains location accuracy and consistent operation. It will work at the same speed as it does in ideal conditions. The machine is extremely fast and productive. For surfacing operations on a Class 1 railroad, the Drone can tamp twice as many ties as the machine it is following, in effectively the same amount of time. Currently the prototype machine is working behind a new Mark VI
tamper which is achieving peak speeds of 15 ties per minute (double tamping every third tie). The Drone double tamps both ties skipped by the machine ahead. While the Drone cannot quite reach double tamping speeds of 30 ties per minute, it is relentless in operation and does not fall behind. This allows one operator to double tamp over 4,000 feet of track per hour.

The Drone would not work without very accurate tie finding technology, which it has in AutoMag. By comparing tie locations found on both machines, the Drone is able to continuously refine its location so that it knows exactly where it is in relation to the machine ahead to within a fraction of an inch for mile after mile of operation. This is one of the key enabling mechanisms at work on the Drone.

The Drone is in constant radio communication with the machine it is working behind. Up to 10,000 ties are memorized on both machines allowing either or both machines to be interrupted during work whenever necessary with a lock out, tag out. On restarting, all previously known tie locations will be restored and operation immediately resumed with locations fully synchronized without requiring any specific action on the part of the operator on the lead tamper.

Several technologies, strategies, optimizations and automatic behaviors have been incorporated on the Drone. Some examples are:
- Wireless machine to machine radio communication
- Radar units to warn and protect workers
- Computer control of work head squeeze rates.
- Computer control of system pressures

The benefits of using an unmanned chase tamper in a skip tamping process are well defined and measureable. The most significant benefit is increased productivity with one less operator. Other potential, but not yet as well defined, benefits include increased track quality, reduced lost time injuries (due to one less man on the railroad with a potential for injury), and other benefits that have a smaller impact on the economic benefits.

With the successful implementation of an autonomous tamper, and realized increases in production, safety and economic benefits, future endeavors in unmanned work equipment show promise.