FUTURE FORESTS RESEARCH

HARVESTING TECHNICAL NOTE

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Integration of Harvester Data and Geospatial Information

Summary

Modern forest harvesters and processors have the capacity to generate and record a lot of data using their on-board sensors and computer using a data protocol called StanForD. The types of StanForD output files identified as the most useful for harvest and forest management contain detailed data for stems, cut logs and time. When work statistics and Global Navigation Satellite System (GNSS) functions are enabled in the on-board computer, geospatial coordinates and time stamps are also included in the files. This offers opportunities to generate not only detailed production reports, but also machine productivity assessment, navigation tools to aid the machine operator, and forest inventory reconciliation. A geo-referenced record of all trees harvested in a forest also provides stand and log quality data for both silvicultural management of subsequent rotations and research purposes. Limitations to wider use include improving geospatial data precision under the tree canopy, determining the most appropriate location on the machine for the GNSS receiver, and improving measurement system capabilities, operator training and manufacturer/dealer support.

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INTRODUCTION

Logging productivity monitoring and the convenience of integrating technology for monitoring productivity has been documented previously (Marshall, 2008 and Marshall, 2010). The computer control and measuring system of modern harvesters can record detailed production data of each harvested tree and corresponding cut logs. When harvesters are equipped with a Global Navigation Satellite System (GNSS) receiver, these data include a locational reference and (in some machines) a time stamp.

In New Zealand harvesting operations there is a trend towards mechanisation, mostly for productivity and safety reasons, although current use of mechanised felling is relatively low at 26% of surveyed operations (Visser, 2013). As the technology develops to allow contractors and forestry companies to overcome terrain and tree size limitations, the use of harvesters will increase. Using harvesters for felling and processing in the stand has some potential advantages, such as lower environmental impact of cut-to-length (CTL) systems, and the use of the measurement and data collection system to provide valuable information for forest and harvesting management.

Standard for Forest Machine Data

In nearly all modern forest harvesters and processors, data from on-board sensors and computers is recorded using the Standard for Forest Machine Data and Communication (StanForD), which was developed by the research group SkogForsk in Sweden. It is used by most manufacturers and forestry companies, and constitutes a de facto standard for all harvester computers and forest machine communications.

There are about twenty standard file types generated by StanForD (Skogforsk, 2007). For forest and harvesting operation data management, the most commonly used are **prd, apt, pri, drf** and **stm** files.

prd: Production files (primarily harvesting production data). These contain the summary of volume and number of pieces per sort for a given period (e.g. a shift, a day or a week) or harvest unit.

apt: Cross-cutting instructions including price matrices per sort that the harvester uses to maximise the value of each stem or fill a production order.

pri: Production-individual file of harvesting data (length, diameter and volume) for each individual log and stem. When a GNSS receiver is connected, it can also include the geospatial coordinates for each stem.

drf: Operational monitoring data, which covers both work time and repair time monitoring.

stm: Stem files; compressed data for each individual processed stem (tree), including all diameter sections measured at 10-cm intervals. When a GNSS receiver is connected, the coordinates of each tree are included, and some control systems record a time stamp when the tree was cut. Some manufacturers allow **stm** files to be recorded as individual files for each stem, or a multi stem file, whereas others do not have the option and have one format only.

StanForD uses two codes (called 'variable' and 'type') to standardise data capture for specific parameters, followed by the actual data that is being recorded. A StanForD data record for an individual tree along with an explanation of the data is shown in Table 1.

Table 1: Part of one stm file for a single harvested stem and explanation of the data

110 2 1~**270** 1 27~**270** 2 0~**270** 3 27~**38** 1 J Cabrera~**38** 4 0~**38** 5 0~**523** 1 3257956~**523** 2 2~**523** 3 5740183~**523** 4 2~**523** 5 101~**523** 6 20140522212527~

Register	Information contained
110 2 1~	Species code, e.g. 1 = Eucalyptus.
270 1 27~	Stem identity = 27th tree harvested.
270 2 0~	0 means no information contained.
38 1 J Cabrera~	Machine operator = J Cabrera.
523 1 3257956~	GNSS Latitude = 32.57956º
523 2 2~	Latitude 2 = Southern hemisphere
523 3 5740183~	GNSS Longitude = 57.40183º
523 4 2~	Longitude 2 = Western hemisphere.
523 5 101~	GNSS Altitude = 101 m above sea level.
523 6 20140522212527~	Felling date and time: year 2014, month 05, day 22, hour 21, minute 25, second 27.

For the newer version of StanForD (StanForD 2010), some file types have been renamed as shown in Table 2. Nevertheless, the data contained in both versions is similar (Arlinger *et al*., 2012).

Table 2: Equivalence between StanForD and StanForD 2010

StanFoD file type	Equivalent file in StanForD 2010	File name in StanForD 2010
pri	.hpr	Harvested production
drf	.mom	Operational monitoring data
stm	.hqc	Harvesting quality control

Reading and manipulating StanForD files

While StanForD files contain useful data, the process of extracting, storing and analysing the data can be complex. Some companies produce software that makes reading, creating and editing StanForD files easier. For example, John Deere and Waratah use SilviA and Ponsse uses the harvester control software itself. In addition, software developed for managing operations and fleet control such as TimberOffice[1] from John Deere and Ponsse Opti from Ponsse can also be used. All have extra licence costs.

All software has limitations with regard to the type of analysis the user can do. For instance, none currently has the capability of providing work statistics for shorter periods than one shift (one day's work for a single operator). Moreover, they can normally open only files generated by their own machines and are designed to read and manage limited file types, normally **prd**, **apt**, **drf** and sometimes **pri** files.

All StanForD files can be opened as text files; therefore, the user can extract the file and access the "raw" data. Managing the files directly gives the forest practitioner flexibility to take advantage of the recorded information.

Although each file type contains standard data, the exact number of variables in each file varies between manufacturers. Table 3 compares the data contained in **stm** and **pri** files from different manufacturers. The order of variables presented in a file can also differ between control systems. As such, files from each manufacturer must be managed separately.

[1] http://www.timberoffice.com/english/

Table 3: Number of variables contained in two types of StanForD files for different manufacturers

Type of file	Control system	Machine manufacturer	Number of variables in the file
stm	Dasa 5	Satco	46
	TimberMatic	Waratah	42
	Opti4G	Ponsee	87
pri	Dasa 5	Satco	67
	OptiPlus V5	Woodsman	64
	TimberMatic	Waratah	56
	Opti4G	Ponsee	69

It is important to learn what the StanForD variables and types mean to understand what is in the files and decide what data is useful. All the instructions are available on the Skogforsk website[2]. This study looked at the files that have geospatial and/or time stamp information, which are **stm, pri** and **drf** files.

Figure 1 presents an example work flow for extracting data from StanForD files.

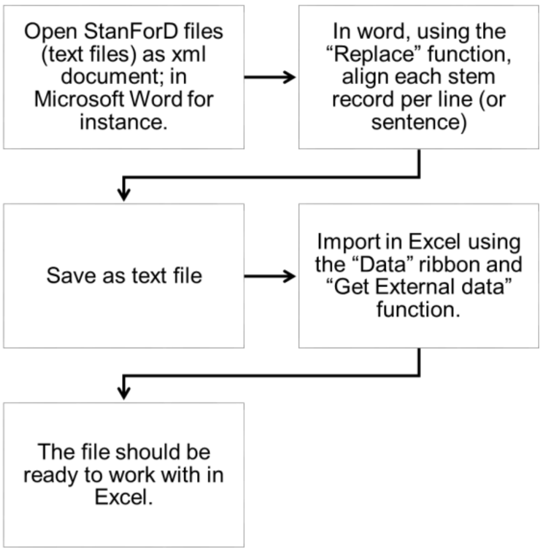

Figure 1: Sample process for extracting data from StanForD files

Once the data is in tabular form (as shown in Tables 4 and 5 overleaf), it can be processed in a Microsoft Excel spreadsheet, analysed in a statistical package such as R, or mapped in a GIS such as ArcGIS or QGIS.

PRACTICAL APPLICATIONS

The opportunities for improved management include provision of detailed production reports and machine productivity assessment, navigation tools for the machine operator and reconciliation of production with forest inventory data.

Production Reports

The most obvious use of harvester data is reporting daily (or shift level) production, which is readily available in the **prd** summary files. These files could also be used for production planning, truck scheduling and optimising logistics, or for paying the contractor. However, combining the StanForD data with the geospatial data (i.e. locational coordinates and time stamps) provides opportunities to improve forest and harvesting operations management. The opportunities presented in this report are (a) productivity assessment and monitoring, (b) navigation tools to aid the machine operator, and (c) reconciliation of forest inventory data.

Productivity Assessment and Monitoring

If the GNSS function is enabled, the machine records x, y and z coordinates (longitude, latitude, and altitude) and time stamp in **stm** files when a tree is felled or starting to be processed (Table 4). Furthermore, when the work statistics function is enabled, it is possible to have a record of all "sub activities" (e.g. working, travelling, idling, etc.) performed by the machine (Figure 2). This data is recorded as **drf** files.

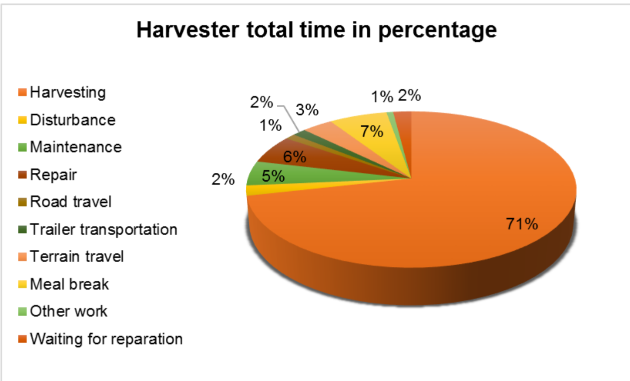

Figure 2: Proportion of time for the various activities performed by the harvester.

[2] http://www.skogforsk.se/en/About-skogforsk/Collaboration-groups/StanForD/

Table 4: Information from stm files showing individual trees, time stamp and calculated processing time information

Stem ID	Longitude	Latitude	Altitude (m)	DBH (mm)	Vol (m^3)	Commercial height (m)	Top diameter (mm)	Date & time	Stem processing time	Species
2	-57.40200	-32.57951	95	301	0.66	18.83	132	2014-05-22 20:47:40	00:00:37	E. grandis
3	-57.40199	-32.57952	99	145	0.13	12.83	67	2014-05-22 20:48:17	00:02:14	E. grandis
4	-57.40200	-32.57951	99	354	1.49	30.53	65	2014-05-22 20:50:31	00:01:49	E. grandis
5	-57.40202	-32.57953	104	346	1.36	25.67	105	2014-05-22 20:52:20	00:01:20	E. grandis
6	-57.40201	-32.57953	102	284	0.88	24.11	97	2014-05-22 20:53:40	00:00:31	E. grandis

Table 5: Information extracted from drf files showing work statistics and productivity information

Start time	End time	Volume (m^3)	Number of logs	Fuel consumtion (l)	Driven distance (m)	Work type	Number of stems cut
2014-05-22 20:25:44	2014-05-22 20:39:11	0	0	3	1882	Road travel	0
2014-05-22 20:39:11	2014-05-22 20:55:58	5.33	28	6	80	Harvesting	8
2014-05-22 20:55:58	2014-05-22 20:58:31	0	0	2	47	Terrain travel	0
2014-05-22 20:58:31	2014-05-22 21:54:24	23.8	162	20	83	Harvesting	49
2014-05-22 21:54:24	2014-05-22 21:55:32	0	0	0	7	Terrain travel	0

From this breakdown it is possible to determine effective time or productive machine hours (PMH). They are typically recorded in predefined time intervals; for instance five (PMH_{05}) or fifteen minutes (PMH_{15}) respectively (Table 5).

A time stamp (from **stm** files) of when the tree was cut is recorded. By subtracting the time for consecutive trees it is possible to obtain processing time (second to last column, Table 4). This data from **stm** and **drf** files can be integrated for performing time studies. It can even be automated for systematic performance monitoring, allowing the user to isolate specific periods and compare performance in different situations such as: harvesting an area affected by windthrow; individual operator performance; progress in training; or adjusting expected productivity models related to multiple factors.

Overlaying and cross-analysing productivity against topographic or soil maps can assess the effect on performance on different slopes and soil types.

Navigation Tools for the Machine Operator

Geospatial data such as machine position at the time of felling and machine tracks can be recorded and displayed in real time on the machine's computer screen (Figure 3). The advantages of having an on-board navigation system capable of displaying geospatial information have been described by Marshall (2012). Similar to the recently launched HarvestNav on-board navigation system, several harvester control systems also have a navigation system capable of displaying a range of base layer maps. Base layer maps can include raster and vector data such as digital elevation models (raster feature), stand maps (polygon feature), power lines (line feature), etc.

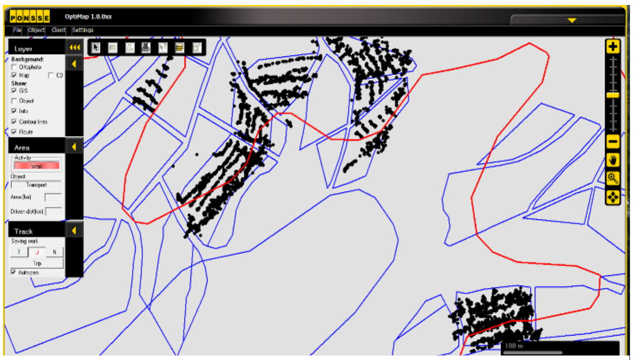

Figure 3: Screenshot of OptiMap (Ponsse) navigation software showing layer information display. The points represent tree records, red lines are contour lines, blue polygons are stand boundaries.

The operator can navigate with a map displaying stand boundaries as well as restricted or dangerous areas based on the outputs presented on the machine's computer screen. Additional functions such as

recording points (e.g. features of interest) and calculating areas are available in some of the systems. Optional additional capabilities include communicating wirelessly with other machines, such as the forwarder, to send information of stock pile location, or routes so a forwarder uses the same route for extraction as the harvester (Figure 4). All of these commercial applications have a licencing cost. Examples of such systems are TimberNavi from John Deere and Waratah, OptiMap from Ponsse, and Dasa geoinfo (from Dasa and fitted on several different makes of machine).

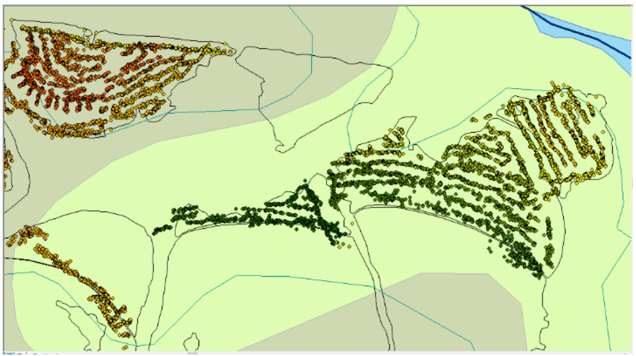

Figure 4: Harvester machine tracks plotted on ArcGIS overlaid on stand and soil maps. Red represents the start of activity, yellow intermediate stages and green last registers.

Forest Inventory Reconciliation

Data collected in the **stm** and **pri** files can be useful for assessing the real volume harvested within a stand, and to reconcile with inventory predictions and check or validate the accuracy of the prediction models.

Using a sample data set, Figure 5 shows not only the total number of trees harvested and their spatial distribution, but by combining the tree volumes in a GIS it is possible to generate a stand volume density map. It can show that specific areas in the stand have outperformed others in terms of total growth. Overlaid on soil maps, or using slope and aspect functions in GIS, it is possible to research reasons for the variations growth characteristics. Figures 5 and 6 were created in GIS software using GNSS-enabled StanForD files, specifically the **stm** and **pri** files.

An additional step might be to create a map of the variation y volume recovered across the terrain, based on the average value of neighbour cells (Figure 6). It would show which area of the stand is producing the highest accumulated volume.

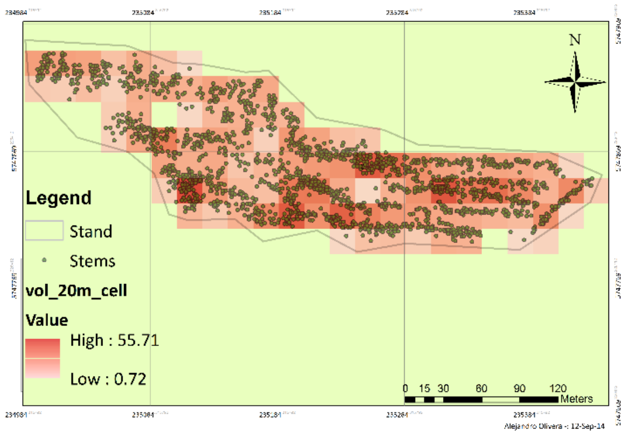

Figure 5: Forest volume map showing detail of volume (m^3) within a 20 by 20m cell. The volume increases from clear to darker cells.

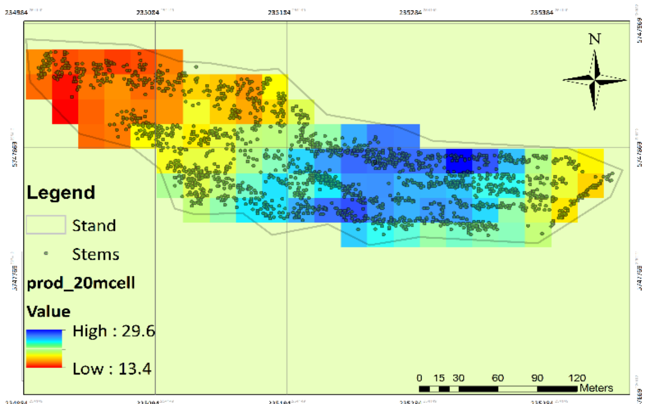

Figure 6: Stand map where points represent individual trees and the colour of each square represents the productivity in m^3 from low volume (red), to moderate volume (yellow) to high volume (blue).

Further Opportunities

With a geo-referenced census of all trees harvested in a forest, the data can yield further advantages for forest management and research. The following examples illustrate some of the potential uses of this data.

- Using the profile of each stem measured at 10-cm intervals (Figure 7) in different area of the stand, more exact taper function can be generated.

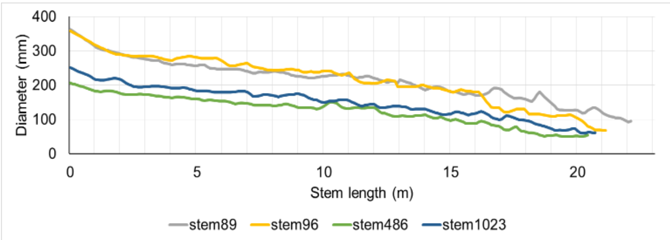

Figure 7: Profile of four stems plotted in Excel from stm files

- Mapping and assessing forest characteristics and their variation across the area would be a useful feedback for silviculture. It would help understand productivity patterns by cross analysing with soil maps and topography maps.
- Check models; Figure 8 presents an example of the data from about 2000 stems harvested over four days in a *Eucalyptus maidenii* plantation in Uruguay showing both height and DBH distributions, including their best fit regression.

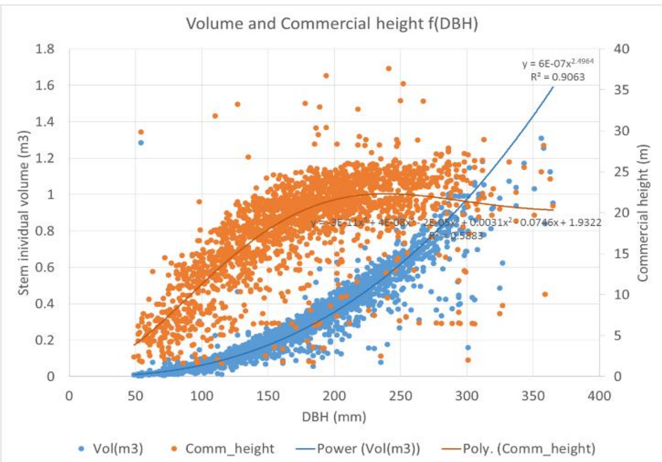

Figure 8: Graph of volume and commercial height as a function of DBH. Data from stem files.

Using the time stamp, the stem data can also be synchronized with other measurement systems – for example wood quality (stiffness) measured by acoustic velocity with a device fitted on the head (e.g. Hitman PH330).

The above listed opportunities are possible as long as the harvester is cutting and processing in the stand. For machines processing on the landing, a GNSS itself would add limited value. However, the opportunities regarding machine productivity can be realised since the time stamp on **stm** files, at the start of processing a stem, is recorded only if the GNSS function is enabled.

Limitations

GNSS accuracy can be a major issue if we want to have a high level of location accuracy for the harvested trees. Two factors determine the actual tree position accuracy; the signal quality and the location of the GNSS receiver on the machine.

- Signal quality: Common handheld and tracking GNSS are normally cheap and provide accuracy up to fifteen metres, whereas a high grade GNSS with the capacity of correcting the signal in real time or post processing can achieve an accuracy of two meters or lower.

- Location: The GNSS receiver location is typically in or on the cab. The tree being felled can be up to 10 meters away from the cab. While the GNSS (or at least the aerial) can be mounted on the boom or the harvesting head itself, it is then exposed to frequent damage and/or problems with the wires going back to the on-board computer. Adding a digital compass can provide for an offset estimation if synchronised with the time stamp.

To date NZ experience is limited to a low grade tracking GNSS installed in the cab of the machine. With limited direct application in New Zealand for either the on-board computer capability of tracking, our experience in New Zealand has been limited. While there is desire to capture data specific to NZ conditions, some machines don't comply with StanForD, while others are not capable of connecting to a GNSS. Likewise, some systems do not record **stm** files, whereas others do not have the time stamp option set up. Obtaining good data for research or operation will require manufacturer support to ensure our harvesters are configured for it, as well as operators who are prepared to ensure that the recorded data records are stored, downloaded and set for analyses.

CONCLUSIONS

Harvesters are not only timber processors but also powerful data recorders. Several opportunities arise from both the use of StanForD files and the navigation tools from GNSS-enabled harvesters. Taking advantage of these opportunities helps not only the harvesting operation itself but also the whole forest process. Realising the benefits of this system depends on:

- a good understanding of how the StanForD standard generates data, what data is available and how to read and make sense of the data;
- a thorough use of the machine measurement and control system with frequent calibrations and quality control;
- a good understanding of the limitations of the system; and
- the motivation to use, and gain perceived value from the use of, such a tool.

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