RADIATA MANAGEMENT TECHNICAL NOTE

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Predicted End-product Quality

Summary

Product quality modelling is a key component of the Intensive Forest Systems (IFS) programme at Scion, and one that is less well understood than growth and yield modelling, and even wood properties modelling. While most aspects of wood quality are created in the forest, information on product performance, rather than surrogate measures such as density or microfibril angle, is required by processors and end users. In this regard, growers, end-users and producers of wood products often have differing criteria for quality. Therefore it is likely that forest growers do not totally understand end-users' expectations around product quality, or fully appreciate that sawmills are not the final customers for their products. For example, will a quality log (i.e. straight with small branches) necessarily yield quality sawn timber (i.e. acceptable mechanical properties and a low propensity to warp)? While this criticism may appear unwarranted, do forest growers know what proportion of the products that are produced from the trees is rejected by end-users, or the economic cost of rejection?

Understanding product quality enables forest managers to evaluate different silvicultural regimes and to determine whether their products meet the needs of end-users. There are a number of approaches to modelling quality, ranging from empirical relationships between tree-level attributes and product quality, through to mechanistic models that predict multiple product performance attributes from intra-stem models of wood properties. The approach being developed within the IFS programme falls into this latter category. In this technical note, the rationale for why product quality simulation is needed along with an overview of this framework being developed in the IFS programme is presented.

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Why predict product quality?

Satisfactory performance is of critical importance to the producers and users of wood products. Clearly, performance requirements will vary depending on the product being considered, e.g. structural timber, cladding, or mouldings, but in all cases if the product does not meet the end-users' specifications or expectations they will not use it. For example, Johansson *et al*.[1] report that in Sweden, building contractors have stated that the quality of structural timber has deteriorated over some years. In this case the problem was mostly excessive distortion and as a result timber was losing market share to other products. Problems with excessive distortion are not unique to Sweden and have been noted in many countries, including New Zealand[2].

Johansson *et al*.[1] refer to the "broken chain from forest to building industry" and stress that in order to develop a future supply of high-quality timber, communication between forest growers, wood processers and end-users of wood products must improve. This is made more difficult by the fact that the views of what constitutes quality differ between these three groups. For example, high quality logs from a foresters' perspective, which are straight with fine branching, will not necessarily yield high quality timber from an end-users' perspective. Ultimately, the true value of a log is determined by the value of the products that can be obtained from it. Therefore, to improve their profitability it is important that forest managers understand the connection between forest management and product quality and that any process optimisation is focussed on end-user quality-related variables rather than on substitute parameters[3]. This information is also needed by wood processors looking to make strategic decisions. In this case, they need to know that there is a sufficient quantity of forest resource in the supply catchment that will enable them to produce economic yields of products that meet their customers' requirements.

Being able to predict product quality is critical for getting New Zealand-grown radiata pine into new products and new markets. For example, one of the key areas where timber can increase its market share is in low to medium rise non-residential construction (i.e. less than six stories). While this type of construction is well suited to timber and there are several exemplar commercial buildings containing a high proportion of timber elements (e.g. the Nelson-Marlborough Institute of Technology), the use of timber in this part of the construction sector is generally low. Part of the solution to this problem is developing products that have the performance

characteristics required by end-users, so that timber can compete effectively with alternative materials. Even in the case of many engineered wood products, performance characteristics are a function of the underlying wood properties.

What is the cost of poor wood quality?

The short answer to this question is that we probably don't know the true cost. As a sector we should know where value loss is occurring, along with those areas where there are opportunities to add value. Such an analysis will also constitute a business case for why we should model product quality and for the broader IFS programme.

Business cases have been developed to support government and industry investment in both WQI Ltd[4] and RPBC Ltd[5]. In the business case for WQI, it was estimated that the industry was losing at least $200 million per year due to wood quality issues. This figure included only the losses due to the downgrading of finished wood products and sub-optimal use of material. Losses due to material being rejected by the customer and the opportunity cost of having customers use other products or species in place of radiata pine were not included. It was estimated that getting radiata pine into selected higher value markets could be worth at least $400 million per year. As well as presenting these figures to support wood quality research, the WQI business case also supported the need for product quality research through the following statement:

"Higher value markets will produce more revenue for New Zealand manufacturers and producers. However, the challenge to enter higher value markets lies in being able to guarantee product performance. The reputation of radiata pine, and indeed wood, has suffered as end users have found unsatisfactory performance for some applications."

Part of our effort in product quality modelling within the IFS programme should focus on better understanding value loss. Presumably it would be relatively straightforward to get information from sawmillers that quantifies the value loss that occurs from downgrading timber due to excessive warp, inadequate strength and stiffness, and visual defects such as large knots, resin pockets and internal checking. However, the real challenge in developing any business case is to identify the new opportunities for wood products that would arise if we could overcome the real and perceived concerns by end-users over product performance.

How to predict product quality

There are several different approaches to predicting product quality, which can be broadly grouped into two categories:

1. Empirical (based on statistical relationships between tree/log characteristics and end product properties)
2. Mechanistic (based on strength of materials theory)

The intention here is not to present a comprehensive review of all the studies that have attempted to predict product quality, but to highlight a few selected studies to show the types of approaches that have been taken. There is no single "right" approach to this problem.

Empirical approaches range from single regression equations to predict the performance of individual boards, or groups of boards, through to modelling frameworks that link tree growth, wood properties and product performance. Regression equations have been used to predict the strength and stiffness of individual boards from tree and stand factors[6], the stiffness of boards from stress wave velocity measurements made on standing trees or logs[7-10], or the distortion of timber from characteristics measured on individual logs[11]. More complex empirical modelling systems that link wood properties and/or product quality to tree growth and forest management include WinEPIFN[12], STANDQUA[13] and SAWMOD[14].

One of the limitations of the SAWMOD module (available within STANDPAK) is that it predicts sawn timber grade recovery solely from external log characteristics. Internal wood properties and their effects on product performance are not considered. Therefore, it predicts that two logs that have the same external characteristics will produce exactly the same sawn timber grade outturn, even though their internal wood properties could be markedly different. Furthermore, empirical models are only strictly valid for the underlying population for which they were developed, i.e. they are not particularly flexible. For example, how robust are SAWMOD predictions likely to be if the underlying resource, sawing patterns and timber grades have changed since it was developed?

Mechanistic approaches attempt to overcome these limitations by modelling from underlying wood properties. These can either be a full list of material properties as used by Ormarsson *et al.*[15] to simulate the distortion of a drying board, or structural

properties (wood qualities) from which these material properties can be inferred. The PQSim model that forms the central component of the product quality predicting system being developed within the IFS programme takes this latter approach. As input it uses high resolution three-dimensional information on wood density, microfibril orientation, chemical composition and grain orientation, which will be provided by mathematical models fitted to data obtained from destructive sampling. These models are intended to predict the intra-stem and inter-stem variation in these properties. This level of detail is required if the goal is to be able to predict distortion (the main performance issue identified by end-users), as this is caused by fine scale variation in wood properties.

Another key challenge with modelling distortion is that it needs to be done at the individual tree/log level rather than at the stand level. This is because the average level of distortion is of no interest to the end-user. Their interest is in the most severely distorted boards, specifically the proportion of boards whose distortion exceeds a certain threshold. By focussing on distortion, the approach taken in the IFS project will also include timber stiffness, which is a key performance measure for structural timber. A final stage will be to link the findings with routine stand inventory systems for foresters and stem/log scanning for processors.

Fixing the broken chain

To end with, we offer a few suggestions on ways in which we can strengthen the links along the wood value chain and ensure that products made from New Zealand-grown radiata pine meet end-user performance expectations.

Firstly, it is important that the work undertaken within the IFS programme is linked to, and informed by, research done by both the Structural Timber Innovation Company (STIC) and Solid Wood Innovation (SWI). We also need to engage with architects, engineers and builders who work with timber, so we can learn more about the potential markets for timber and the performance characteristics required to access these markets. At the other end of the supply chain, it is also important to work with tree breeders (e.g Radiata Pine Breeding Company) to ensure that the implications of future selections on product performance are understood.

Secondly, we need to be aware of similar research projects conducted in other countries. Two relevant projects that are looking to model along the supply chain from forest to product are FlexWood[16] and ForValueNet[17]. In particular, the Canadian ForValueNet project is combining three-dimensional wood properties models with sawmill simulation software and bringing them together in an optimisation framework in order to determine how to realise the maximum value from individual trees.

A fully-fledged product quality simulator that is linked to a growth and yield prediction system would enable similar optimisation studies to be undertaken in radiata pine. This would not only allow growers and processors to optimise the value of an individual stem, but would inform growers on how to manage forests in order to produce products that meet the requirements of end-users.

Finally, it is possibly a touch ironic that having access to a product quality simulation system would be of immense value in preparing a business case to support its development!

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