How to set up a NIRS networking system for agricultural products

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Networking is the working together of a series of instruments, usually from a single control point, to achieve the common goal of controlling an operation accurately. The principle of networking is based on central control of the accuracy of the on-site instruments, and monitoring of the accuracy and precision (reproducibility) of the on-site instrument(s), all of which carry the same calibrations. The on-site operator may have no access to the system for adjusting the instruments. Most large-scale networking operations have been established by commercial and government establishments that are involved with large-scale grain-handling. These have been developed in-house. Although there is an extensive bibliography on NIR technology, there is very little published information on NIR network development.

Calibrations developed by one centre can be shared with other locations that use the same type and model of instruments. Another aspect of networking is that instruments can be located at strategic points in an industrial plant, and by networking to one computer all aspects of the process can be regulated and controlled, including monitoring of the composition of raw materials, the efficiency of blending during processing, and the composition of the final products.

Successful application of near-infrared (NIR) networking depends on the integrity of ten factors:

- reference or "Check" samples
- a system for distribution and use of check samples
- a dependable laboratory for reference testing
- a set of reliable instruments with reliable calibrations
- a central computer (this can be a main-frame, PC, or a lap-top)
- software for monitoring purposes and applying corrections to instruments
- software for development of calibrations
- software for operation of the network
- the person in charge of the networking operation
- education and training of staff in all aspects of the operation.

The presentation will discuss the individual steps, together with the process of establishing a check sample system.

Networking applications can be divided into two main categories. These are:

1. control of the accuracy and precision of instruments
2. access to data throughout the network for control of the operation

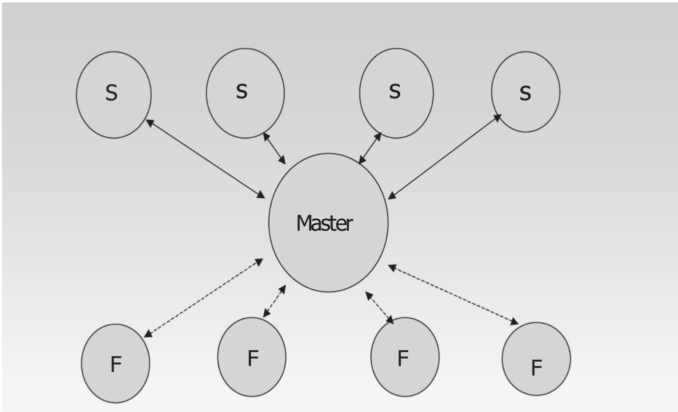

Figure 1. The networking concept. Legend: Master = master instrument at central laboratory; S = "satellite" or "slave" instruments at receiving or shipping points; F = flour or feed mills (optional participants).

There are three main forms of networks (not in order of importance). The first type consists of a series of instruments connected to a central computer. Figure 1 illustrates this type. The S circles represent "satellite" instruments at delivery or shipping points. The F circles represent a series of flour- or feed-mills, which can be controlled from the central computer, as an optional service to the industry. The instruments would all be controlled from the master instrument, via the central computer, and the instruments monitored on-site by check samples. The optional service to the mills would include supply of the same check samples used by the control centre.

The second example is a network that includes farms and grain delivery points (Primary elevators).

The farms are networked with the receiving/shipping points, in this case elevators (silos), and would provide the elevators with an estimate of their holdings of the amounts and characteristics (grade and protein content) of grain in storage (Figure 3). The primary elevators can call grain of the grade and protein content required to compose unit trains, which would streamline grain-

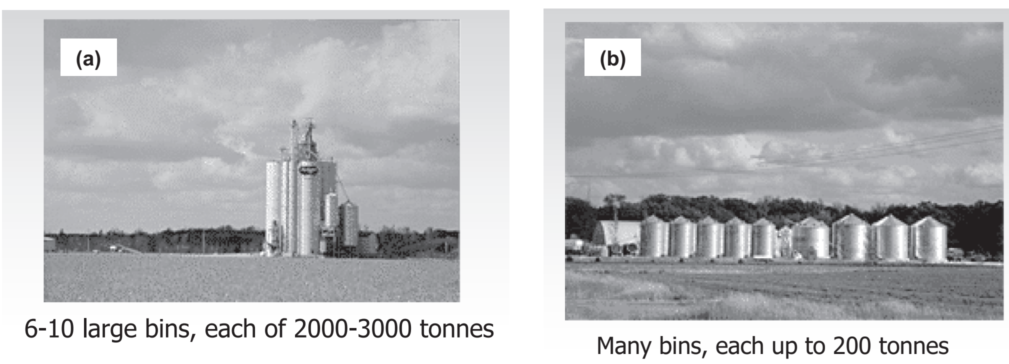

Figure 2. (a) A country elevator in western Canada and (b) On-farm storage in western Canada.

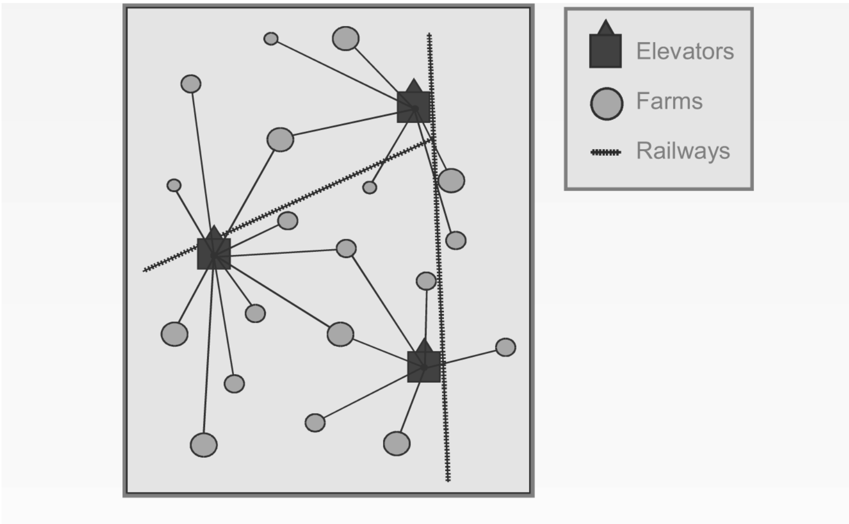

Figure 3. Farm/Elevator network.

handling and marketing. The concept calls for testing grain at the farm level, which is achieved by farmers sampling at harvest-time, and providing samples for the elevators.

This system is actually operating in western Canada. The elevator companies employ staff to collect samples from farms. The concept requires training of farmers to collect representative samples at the time of harvest. Many farmers have installed sampling attachments to their augers. Terminal shipping points can in turn contact primary elevators to load trains with grain of the required class and grade, thereby streamlining the entire system.

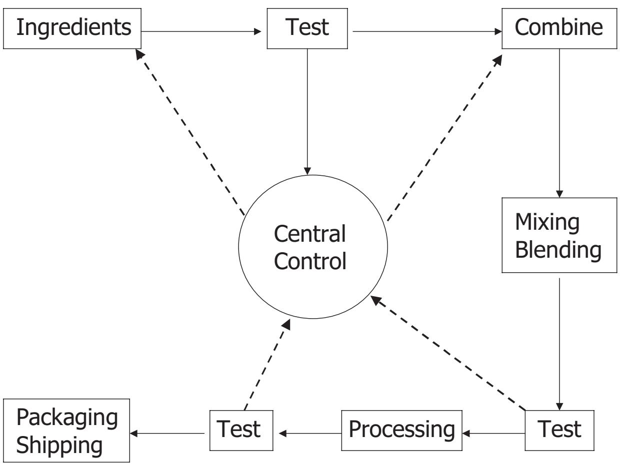

Figure 4. Networking a feed-processing plant using NIRS instruments.

Another type of networking is that instruments can be located at tactical points in an industrial plant. By networking to one computer all aspects of the process can be regulated, including monitoring of the composition of raw materials, the efficiency of blending during processing, and the composition of the final products Figure 4).

Industrial processing plants such as flour-mills or feed-processing plants can install NIR instruments at strategic areas in the plant, and control them through a network operated from the plant control center. Data from these instruments enable the processing plant to maintain consistent product production from the composition of raw materials to that of the finished products. Many of this type of network operate in the feed-and-food-processing industries. The steps in establishing a NIR network are summarized in Table 1:

Table 1. Steps in establishing a NIR network system.

1. Determine whether a NIR network will be of economic and/or practical benefit to the operation
2. Prepare a budget for setting up the network
3. Identify the control centre
4. Identify the method for networking (e.g. modem, e-mail, wireless communication, etc.)
5. Identify a person to accept responsibility for running, monitoring, and controlling the entire operation
6. Identify locations for instruments (at remote locations, or at strategic locations within a processing plant)
7. Install dedicated telephone line, or Local Area Network (LAN) system. Most modems are used with telephones
8. Identify reference methods and reference laboratory
9. Identify the instruments to be used
10. Identify the system for monitoring (e.g. frequency of check sample testing, system of sample distribution, use of on-site testing, etc.)
11. Identify source of check samples
12. Prepare check samples
13. Identify system for distribution of check samples
14. Identify method for correction of instrument deviations
15. Identify the Master instrument
16. Assure that all satellite instruments or sensing heads are functioning properly
17. Standardize all satellite instruments to Master instrument
18. Develop or acquire software for operation of network
19. Train staff in use of network software
20. Test network using limited number of locations
21. Develop and apply corrective measures to system, as necessary
22. Verify that corrective measures have been successful
23. Extend the network to all locations
24. Test networked instruments at all locations
25. Prepare a detailed step-wise manual for operating the system for use in training new staff, and ensuring that all locations are using exactly the same procedures

These steps are not in order of importance. They are all important, but step 1 should be considered before any further action is taken. The decision to install a network for monitoring or data access has to be taken in context with the practical and economic consequences of not doing so. The person in charge of the network should be experienced in analytical chemistry and applied statistics. The level of responsibility is very high. The modem system seems to be the most practicable for network control. Most of the large-scale networks are in use in the grain industry, and are used for testing for moisture and protein contents. The reference methods for protein are usually the Kjeldahl, or the Dumas (combustion) method. Capacitance meters are the most widely-used reference method for moisture testing. They are effective up to about 17% moisture content. Above that level NIR reflectance or transmittance instruments are more reliableIt is essential to determine the precision of both reference tests.

Monochromator-operated instruments are generally regarded as the most reliable for networking purposes. Interferometer-operated instruments are very precise, and are also suitable for networking. An instrument is identified to be the Master instrument. This instrument will serve as the anchor of the entire network. All of the other networked instruments are called "satellite", or "slave" instruments. The master instrument is calibrated and monitored by the selected reference methods. All satellite instruments are monitored through the master instrument.

The most successful large-scale networks are operating in the grain industry. These use artificial neural network (ANN) calibrations. The calibrations have been based on thousands of spectra with reference data supplied originally to Tecator, now to Foss, from clients world-wide. The spectral data have been recorded from many instruments, under many operational conditions of temperature, humidity, dust levels, and other variables. The reference data supplied with the spectral data originate from an array of laboratories. A range in average reference data from each laboratory is to be expected, but provided that there is no overall bias in the reference data, the range will add useful variance (a type of "noise") to the data used to compile the ANN calibrations. This will actually help to stabilize the calibrations. The ANN calibrations for protein content have proven to be extremely stable over the last 9 years that they have been used in Canada

The network has to be monitored to maintain the accuracy and precision (reproducibility) of the network. A useful system for monitoring is to send the satellite instruments three check samples every three months. Check samples are prepared to cover the range in protein content expected to happen under normal day-to-day operations, e.g. from about 12 to 15 % with bread wheat types.

Enough bulk check sample is prepared to send sub-samples of all of the check samples to all locations. The samples are issued with an expiry date. Fresh sets of three samples are sent to each location a few days before the expiry date, to ensure continuity. The size of sub-samples is about 600 g, enough for most instruments. Bulk samples are compiled at the central office of the operation, from samples sent from delivery points, such as terminal elevators, where trains are unloaded. All protein tests of check samples are carried out on the master instrument.

The individual samples are blended thoroughly using blending apparatus, such as a Boerner sample divider, to provide a range in protein content of low (e.g. < 12.5 %), medium (12.6 - 14.0 %) and high (> 14.1 %) in the three check samples. These can be identified as A (low), B (medium), and C (high protein) samples. Because the samples are of commercial origin, the overall ranges in the A, B and C check samples will be fairly consistent, but they will be freshly prepared every three months Use of comprehensive calibrations, such as ANN calibrations, in combination with monochromator-driven instruments and modem control with a dedicated telephone line appears to be the most satisfactory system for network operations.

Networking is perhaps the ultimate application of near-infrared (NIR) spectroscopy

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