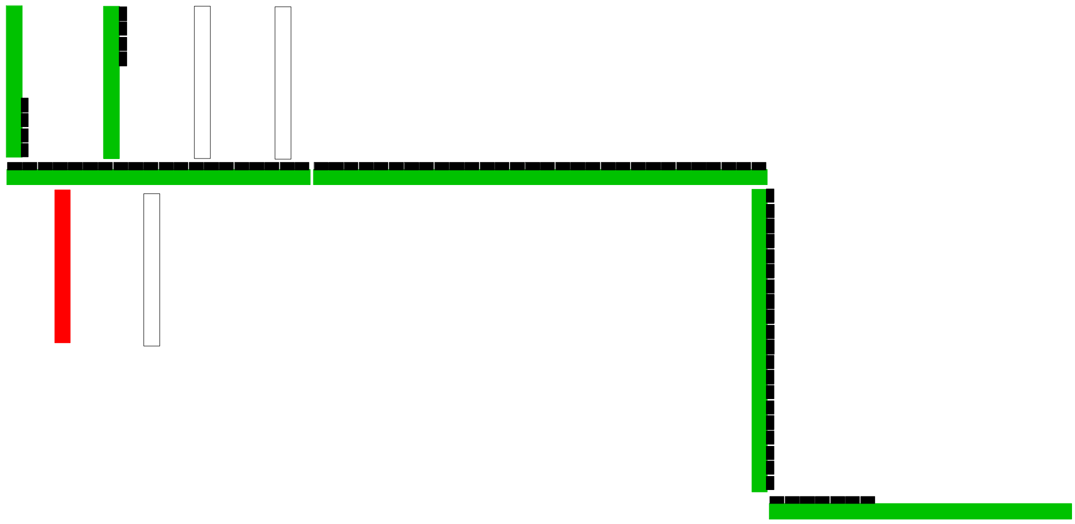
1 What is Conveyor Material Tracking?

Material tracking is method employed to know the position and amount of material at any point in a conveying system. It can encompass three components:-

- Material position indication on SCADA overview screens.
- Overall system loading.
- Flow rate indication at any point in the system.



2 Business Benefits

Knowing where product is positioned on a conveyor system, provides operators with overall site information and allows the control system to perform certain production optimisations. Knowing rates at various parts of a system helps maintainers when analysing problems.

2.1 Production Assistance

- Using SCADA overviews, operators can quickly gain an appreciation of the current status of production or transfer characteristics of the system. The same overviews give supervisors and managers an executive snap shot.
- Although equipment may indicate that it is running (typically green), material tracking indicates that production is occurring.
- Flow rates at transfer points may be graphically trended to show less than optimal production or any potentially trouble causing surges.
- Material approaching control points or equipment can help alert operators that may have been waiting some period with a system running empty. e.g. ship loading or process plants.

2.2 Maintenance Assistance

- SCADA indications identify approaching material and volume when checking transfer points for correct operation.
- Provides a record of conveyor loading in tonnes to check against design parameters.
- Historical flow rates at various points in a system can help identify the causes of material spillages, system overloads and blocked transfer points.
- Knowing loadings can assist when analyzing belt wander problems.
- Allow the empty running of conveyors out of sequence for maintenance purposes.

2.3 Control System Optimisations

- Multi-feed overload protection.
- Transfer chute protection.
- Dust suppression optimisation.
- Optimised conveyor starting periods.
- Non sequential starts on empty conveyor systems.
- Power savings through not operating empty equipment.
- Reverse sequence starting.
- Early warning of approaching material.
- Conveyor pre-loading to minimise new start delays when waiting for end of line equipment to become available.
- Synchronisation for material sampling systems.
- Moisture control & chemical addition

3 Operating Principle

There are two implementations of material tracking. Designers may implement one or both types.

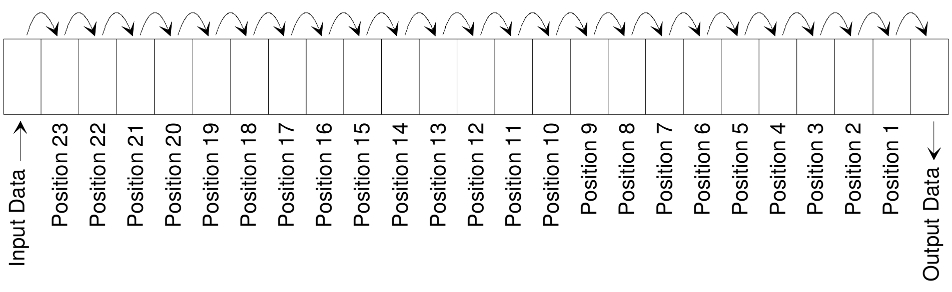
1. Material position indication for production overview. (Tracked digital sections)
2. Flow rate for process information analysis. (Tracked analog sections)

Both methods require that a conveyor be broken into material tracking sections. The length of these sections is dependent of the length of the conveyor, the speed of the conveyor and the resolution of information required. The higher the resolution, the higher the computing power and network speed required. The designer needs to consider resolution versus cost to the system and then the gains to the process. It requires a solid understanding of the benefits and limitations of material tracking before the selection is made.

Typically material tracking systems are updated every 2 seconds. SCADA systems seldom require updates faster than this. Conveyors, travelling at 5 to 6 meters per second, would use a section length of 10 metres. This is the distance that will pass in a two second period.

If the sections are too long, then resolution of information will be lost. If the sections are too short, then the amount of monitored data may become cumbersome and awkward to manage with data displays and communication throughput.

Once a section length has been decided, each section is transferred to the downstream section when a transfer command is received. This is typically generated by a target on a non-driven, rotating pulley. One or many pulses may be used to measure the section distance.

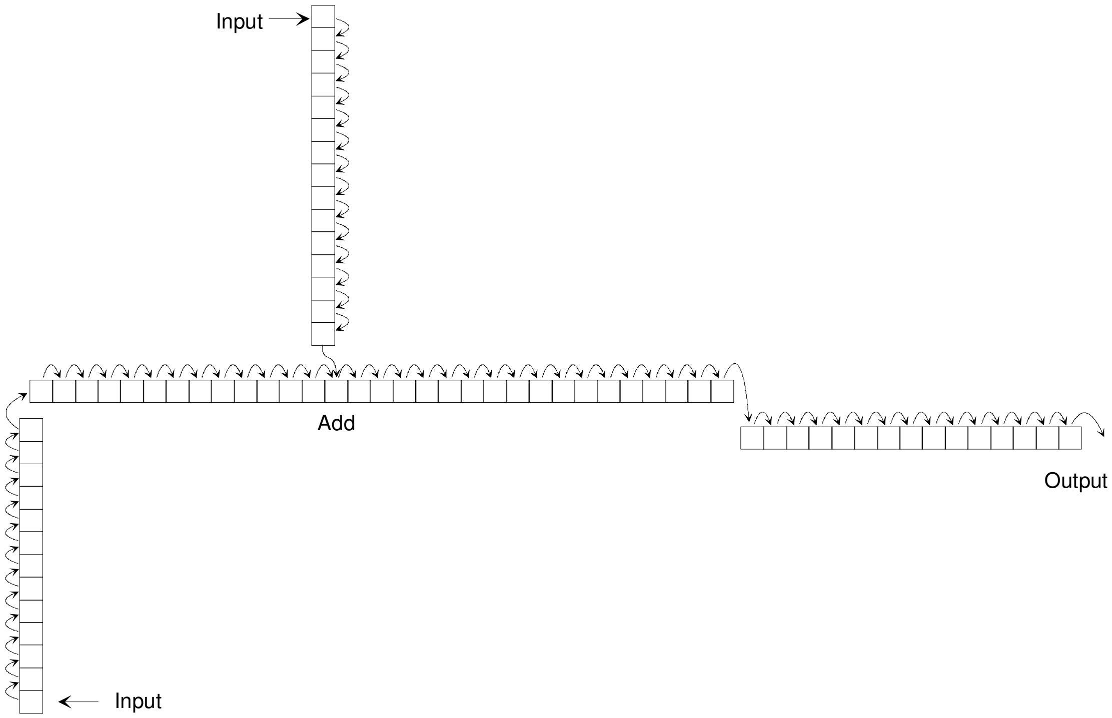


This type of data manipulation is called a data shift register. With each input pulse, data is shifted one position in the array (or sequential group of registers).

Depending on the type of PLC, the tracking array may be implemented as a shift register, a FIFO or an array copy instruction.

Data may be stored in analog form for material flow rate tracking purposes or in bit form for digital indication purposes.

The below diagram illustrates how multiple conveyors data structures can be configured and integrated. These may be in a single PLC or spread across several PLCs.



3.1 Useful Data to Track

As well as material mass per section, it is possible to track other variables or information in parallel.

3.1.1 Product Type Identification

In systems where various types of materials may be transported, material type may be tracked. For example, this may be used to drive water addition in dry material or similarly prevent water from being applied to wet material.

3.1.2 Product Code Identification

In multiple route systems, it is useful to track a unique product, batch or job identifier. This helps to ensure that the correct product is delivered to the correct location. This technique can be used to determine if there is a fault in the transfer system causing incorrect passage.

3.1.3 Accumulated Weight for Virtual Belt Weighers.

Where accumulated weight can be read from a belt weigher at the start of a transfer, it is possible to track the accumulated weight along the conveyor system. This allows the use of virtual belt weighers at any point in the transfer system.

4 What is Required?

- In large systems, networked PLC or other Controllers. These must be capable of transferring data between themselves at a rate that will not compromise the accuracy of the coal tracking. In smaller system a single controller may be in charge of all items.
- Input data in the form of digital indication or material flow rate and conveyor speed.
- A distance pulsing system that increments discrete measuring zones along the conveyor.

- PLC software that is capable of copying arrays of reals or has FIFOs as part of the instruction set.
- A data passing system between PLCs to ensure data is not lost.

5 Input Measurement Techniques

Input measurement is dependent of what type of material tracking is required. For production indication it is only necessary to know if material is on the conveyor or not. For process information analysis material mass or volume is required.

5.1 Production Indication

For production indication only material or no material is required as a digital input or analog signal with a set point.

5.1.1 Ultrasonic Distance Sensors

Ultrasonic sensors measure distance by calculating the time a pulse of ultrasound takes to travel to an object and then be reflected back. The speed of sound in air is approximately 330 m/s, but varies for changes in carrying medium and temperature. Mounted above a conveyor pointing down, they can indicate the depth of material on a conveyor. Their operating frequency may range from 50KHz to 250kHz depending on application.

Certain models provide a single digital switch output to provide material or no material, while others provide a continuous analog signal that indicates distance. If the angle of repose of the material is reasonably constant, and the loading is even across the conveyor, then look up tables that relate distance to flow rate may be built. This will give an approximation for a small investment in capital equipment.

Ultrasonic sensors have a minimum distance they can measure in order to prevent the residual ringing from the transmitter from coupling into the receiver and being falsely detected as a reflected signal. They operate a continuous series of pulses which can often be detected as faint clicks by ear. When mounting these above a conveyor it is important to ensure that they are far enough away from the conveyor so that they are not damaged by surges of material and the minimum sensing distance is not compromised. This may prove difficult in some underground installations.

There is sometimes an issue with this type of measurement where the material reflects the sound wave away from the sensor, rather than back towards it. This is more prevalent on larger particle sized material. Analog sensors will detect a loss of reflection and will indicate a full or zero signal in these circumstances. (usually programmable) It will be necessary to build filtering logic in the PLC to hold the last reading until a good reading comes through. If the condition exists for too long a period, then the sensing must be faulted.

These sensors are also useful for controlling de-dusting sprays, water cleaning sprays and belt scraping devices.

5.2 Process Information Analysis

For process information analysis, either weight or volume is required. By knowing the specific gravity of the product, either may be converted to the other.

5.2.1 Belt Weighers

Belt weighers provide the most comprehensive input for material tracking systems. Typically they provide an analog signal representing the continuous flow rate of the material and an integrator pulse which represents a fixed weight having passed the weigher. This pulse may represent any value from kilograms through to tonnes, depending on the size of the weigher. Many weighers offer serial communications so that additional data, such as accumulated weight, may be accessed. Alternatively if the specific gravity of the material is known, weight may be converted to volume, and volume tracked.

Each material tracking section requires either a weight of material in the section or the average flow rate in that section. Using the weight pulse and storing the amount of weight pulses per tracking section, is a simple method of transferring weigher values to material tracking. It requires the use of simple arrays of bytes or integers. However, this method can suffer from resolution on fast moving conveyors or coarse sensing pulses. It is adequate for determining the total weight a conveyor is carrying. It suffers from accuracy at transfer points and is usually too coarse when determining the material flow rates at various points in a conveyor system.

Belt weighers are accurately calibrated to provide a weight per hour signal. This value is derived from weight at the weigh frame and belt speed. It indicates the total weight that would pass via the conveyor in a 3600 second period. Based on known belt speed, each 10 meter section of conveyor will take a particular period to pass. e.g. A conveyor traveling at 4.5 m/s will take 2.22 seconds to travel 10 meters. A conveyor traveling at 6.3 m/s will take 1.59 seconds to travel the 10 meters. By dividing this period into 3600 gives a conversion factor from “weight per hour” to” weight on the 10 meter section of conveyor”.

Converting Weight per Hour to Weight per Section

$$\text{Conversion Factor} = \frac{3600}{\text{Time to travel each section at full speed}}$$

$$\text{Weight per Section} = \frac{\text{Weight per Hour}}{\text{Conversion Factor}}$$

A further enhancement in accuracy may be gained, if the weight per hour value is averaged over the period with say ten samples. This will select a value every meter which is the span of the weigher. More samples than this, will probably exceed the measuring system’s ability to update the data. This data is stored as a floating point value in the tracking system array. Using this method also has the advantage that the same number that divided the weight per hour signal to provide the weight per section value, can be used to multiply the section value at transfer points to provide a weight per hour indication. During starting and stopping of the conveyor, the sampling rate can be adjusted in accordance with the conveyor speed for better accuracy. e.g. If a conveyor’s sample distance takes 2 seconds to pass at full speed, then take 10 sample at 200m/s and average them. If the conveyor is travelling at 50% speed then the sample rate is modified to every 400m/s.

$$\text{Sample Rate period} = \frac{\text{Full speed rate period x 100}}{\text{Current Speed \%}}$$

5.2.2 Flow Gauges

When conveyors are fed by vibro-feeders or screw conveyors, nucleonic flow gauges mounted across the feed to the conveyor may be used as an input to the material tracking. Some feed mechanisms have inbuilt systems that monitor flow rate through weight. These may also be tapped as inputs to a material tracking system.

5.2.3 Laser Profile Scanners

Laser profile scanners mounted above a conveyor can provide indication of material volume. By knowing the speed of the conveyor and the specific gravity of the material being transported, flow rate in tonnes/hour can be calculated. If the main analysis requires volumetric input, in say cubic meters per hour, then a laser scanner provides the best solution. Some systems may require both weight and volume for optimisation.

5.2.4 Longwall Position and Volume Conversions

Knowing shearer position on a longwall, the size of the forward step and the speed at which the shearer is travelling, a calculation of the volume of the coal falling onto the face chain can be made. If the specific gravity of the coal is reasonably constant, then a weight may be input into a material tracking system. The coal may be tracked along the face chain and the boot stage loader and then to the main gate conveyor. As the longwall steps a set distance each pass, the length of the step may be subtracted from the length of the maingate conveyor. Regular surveying information may be used to update the main gate conveyor length, if cumulative errors affect accuracy.

Note this method may not be suitable if the shearer is removing amounts of stone from the floor or roof. This will affect the average specific gravity of the product and the volume to weight conversion. However it will still give a good indication of coal position throughout the system.

6 Transfer Techniques

6.1 Transfers Between Conveyors

The capacity of conveyors to carry material is based on the following factors.

- Width of conveyor belting. - The wider the belt, the more it can carry. However the wider it is, the more it will cost. (belting, structure, idlers, pulleys etc)
- Troughing angle of idlers. – the deeper the V of the idlers in the carry strand, the more it can carry. Increasing the V will provide extra tension on the outside edges of the belting and therefore decrease its expected life. There is also the issue of spillage as the belting flattens back out to pass through trippers or delivery jibs. The type of material is also a limiting factor for spillage.
- Speed of the conveyor. – The faster the conveyor travels, the more material it can carry. The penalty for increased speed is higher belt tensions and increased wear due to idlers. In order to help the belt track, idlers are installed with a slight angle to square. This produces a slight scrubbing action on the non-carry side of the belting. This wear is logarithmically proportional to speed and therefore extra speed decreases the expected life of the belting, disproportionate to the gain in production.

Issues that arise when transferring material from one conveyor to another include :-

- Full speed running differences between the conveyors. For example a wider belt may be run slower than a narrower belt and still have the same carrying capacity.
- Multiple feeding sources onto a conveyor.
- Material tracking sections may be of different lengths for design convenience.
- Conveyors starting up and therefore not transferring at full rate.
- Time delays through transfer chutes.

The above issues are compensated for by multiplying by transfer ratios as one conveyor's delivery value is passed to the downstream conveyor's input value. The transfer ratio will consist of three components.

1. Output value in flow rate multiplied by the current conveyor speed as a percentage of full speed. This compensate for a ramping up conveyor.
2. Multiplied by the ratio of the difference in speed between the two conveyors. If the downstream conveyor is travelling at twice the speed as the upstream conveyor then only half the equivalent flow rate per unit length will be transferred.
3. Multiplied by the ratio in the difference in the coal tracking lengths. If the pulsing source is too coarse to be exact (say one conveyor at 10 meters and the other at 10.5 meters then this ratio must be taken into account to maintain accuracy.

Generally transfer chutes can be ignored unless their travel time is greater than the time for a tracking section to pass. In this situation an intermediate register may be employed to represent the transfer. Assuming friction in the transfer chute to be negligible on the overall mass of the material, transfer time in the chute can be calculated by the nominal fall period due to gravity.

6.2 Data Passing with Handshaking

The normal process for two conveyors in the same PLC is; when a shift pulse on the downstream conveyor occurs, all data is shift one step toward the head and the head value is lost. A new load in value is copied from the current delivery value of the upstream conveyor that has been modified by the transfer ratio.

When two consecutive conveyors exist in separate PLCs then data must be transferred with handshake bits to ensure that data is updating. In this case when the downstream conveyor generates a shift pulse, all data is shift one step toward the head and the head value is lost. At the same point a data request bit is set in the communications packet to the upstream conveyor. The upstream conveyor responds back in a communication packet with its delivery value multiplied by the transfer ratio and a digital handshake bit to indicate that the data is valid. Once the bit is set, the downstream conveyor loads the analog value into its feed on point. As long as the data transfer occurs before the next shift pulse of the downstream conveyor, then no accuracy is lost.

6.3 Coal Flow at Delivery Points

Blocked chutes and coal surges are issues of concern around all sites. In order to better analyse these problems, materiall tracking is used to record the material flows at the delivery or transfer point to the downstream equipment. This value may logged and viewed with an historical package for analysis..

To convert tonnes per tracked section of conveyor to flow rate in tonnes per hour, the following technique is used. Take the rated belt speed in meters per second and divide it by the length of the coal tracking section in meters. This will give the flow rate in tonnes per second at full speed. Multiply this value by 3600 to give a conversion factor for the section of material to tonnes per hour at full speed.

7 Control Optimisations

7.1 Multi-feed Overload Protection

Where there is more than one source of input material to a conveyor it is possible that excessive feed rates or too many feed sources can exceed the carrying capacity of the conveyor. Monitoring the flow rate at the transfer of every conveyor feeding onto another, it is possible stop at least one of the conveyors and prevent a catastrophic overload.

7.2 Transfer Chute Protection

Some chutes will block if their normal running capacity is exceeded. Blocked chutes will often lead to material spillage and a penalty of downtime and lost production. This best place to eliminate this problem is at the source, but this might not be possible in every case. By tracking a surge, it is possible to slow the conveyor slightly as the surge approaches the transfer point and therefore limit the possibility of the chute blocking.

7.3 Dust Suppression Optimisation

A common method of minimizing dust is to use water misting sprays at transfer points. Running sprays without material, can lead to excessive water in the system. Excessive water can cause the following issues.

- Stockpile slumping. A safety issue and limiting to stock pile sizes.
- Water spillage in the vicinity of application causing slippery or boggy conditions. These conditions may be considered a safety hazard and require additional cleanup and or sumps and pumping.
- Slurry runback on incline conveyors causing material spillage and safety concerns in severe cases.
- Inconsistent moisture in product as water is picked up at the next head of material coming through on incline conveyors. Alternatively slugs of water will be transferred through to the final destination on flat or down hill conveyors.

7.4 Optimised Conveyor Starting Periods

A limiting factor in starting conveyors is the maximum tension allowed in the belting just in front of the drive pulley. The faster a conveyor starts, the higher this tension becomes. Conveyor designers will quote a minimum start period for the conveyor in their design. This value is always quoted with the conveyor fully loaded. If the conveyor is not fully loaded, the starting period may be shortened. Material tracking can indicate the load on the conveyor and therefore control the start period duration.

7.5 Non Sequential Starts on Empty Conveyors

Many systems have sequential conveyor starting. i.e the downstream or outbye conveyor is started first and then once it is almost at full speed, the downstream in inbye conveyor is permitted to start. With many conveyors in a sequence string, a considerable start-up period may develop. If conveyors are empty, then there is no reason why this sequence cannot be more overlapped, so that the startup period is significantly reduced.

7.6 Power Savings Through not Operating Empty Equipment

Power costs on large conveyor systems may be a consideration. Although it may considered that starting and stopping of conveyors increases other maintenance issues, a stopped conveyor consumes very little power. With material tracking, it is possible to optimize running periods. Particular if there are breakdowns or other production delays.

7.7 Reverse Sequence Starting

To save power in the extreme, it is possible to implement reverse sequence starting. In this way conveyors are only run up as material approaches. This requires a high level of reliability in both the conveyors and the material tracking equipment.

7.8 Material Approach Warnings

In situations where operators are waiting for material to be delivered by conveyors, material approach warnings can ensure that operators are concentrating on the task at hand when the material arrives.

7.9 Conveyor Preloading

On long conveyors systems, if there is suitable capacity in the loading system and there is a long travel period to the unloading system, there are time gains to be made in preloading conveyors. This uses the conveyors as time storage so that when the unloading station is ready, material can be delivered quickly.

7.10 Water or Chemical Addition

Many materials require water addition to reduce dust and/or combustibility. Material tracking can help with the water addition to make sure it is accurate for the volume of material passing. Similarly, if chemical additives are required, material tracking can assist in ensuring doses are accurate.

8 Ensuring Reliability

If the decision is made to take advantage of the many control optimisations that are available through product tracking, then question has to be asked:- “What happens if the material tracking fails in anyway?” This would be normally part of the risk assessment that would be included in any design process.

High reliability starts with a good design process.

- Functional specification.
- Detailed calculation and design.
- Design well within maximum parameters of components.
- Failure & Effects Modes Analysis (FEMA)
- Risk assessments on reliability and safety.
- Regular and life cycle maintenance schedules.

For material tracking purposes, a secondary means of material detection can be used to check the material tracking function. Ultrasonic detectors (or other methods mounted above the conveyor) can measure bed depth at critical points and provide a comparison. If an error occurs between the two, then the function that relies on the material tracking can be turned off and the system returned to more orthodox control methods. An appropriate fault will then allow maintenance staff to investigate the cause of the mismatch.

9 Accuracy Issues

Once installed many business functions may become reliant on material tracking. If high levels of accuracy are required, then a considerable amount of engineering attention must be paid to measurement and tracking methods. Even the smallest errors can accumulate in these systems. Designers must trade-off between the installation cost, versus the payback in benefits. Installation cost will be inversely proportional to tolerable error. Accuracy will need to be considered with the overall business benefit in mind. Are high levels of accuracy are required, or can a reasonable percentage error be tolerated?

The following areas have the potential to create errors.

9.1 Accuracy in Operating Parameters

There are five operating parameters that impact on coal tracking accuracy :-

1. Speed of the conveyor
2. Length of each coal tracking section.
3. Number of coal tracking sections in the carry strand of the conveyor
4. Measurement of the number of tones in each coal tracking section
5. PLC's ability to monitor fast changing events within its scan period.

9.1.1 Speed Determination

Speed is measured with a hand wheel tachometer. Although the designer may nominate a belt speed, it is prudent to measure the speed. A 1% error is speed is a one percent error in material tracking. On a four kilometer conveyor, this is 40 meters.

It is important to note that the speed of a conveyor may oscillate sinusoidally due to the elastic nature of the belting and the softness of the drive mechanism. Multiple measurements should taken and then averaged. The measurer should also be aware that the conveyor travels slightly slower at the tail of a conveyor than at the head due to carry strand stretch. This is far more prominent on a loaded conveyor than on an empty conveyor. Due to the nature of the fluid drives and motor rotor slip, loaded conveyors travel at slower speeds than empty ones.

With all of the above factors, it most prudent to carry out all measurements on empty running conveyors. Speed measurements should be in meters per second. m/s.

9.1.2 Length of Section Determination

Once accurate conveyor speed has been determined, two methods can be used to determine the length of each coal tracking section. (Lengths range from 9.6 to 11.9 meters)

Use conveyor speed to determine how long the conveyor will take to travel say 2,000 meters. Set a timer for this period, and use its .TT bit to enable a counter counting pulses while the conveyor is running empty at full speed. When complete, this will provide the number of pulses generated in 2000 meters of travel. Divide the counts into 2000 and this will give and accurate number of meters per count. Select the whole number of pulses that comes closest to give the required meter-age of each section. Multiply the number of counts per section by meters per count to get the length of each coal tracking section. (take section 9.3 into consideration)

9.1.3 Number of Coal Tracking Sections Determination

The most effective method (so far) requires 3 people with radios.

- Using a can of marking paint, a stripe is painted on the belting that can be viewed from the side of the conveyor. It may be prudent to paint a further warning stripe some 30 meters in advance of the marking stripe as a warning to observers. Particularly on the faster conveyors.
- A control person sets up a counter with a temporary enable that can be toggled, counting coal tracking pulses. (In the PLC)

- One observer at the load on point, calls when the marker travels past. This allows the control person to start the counter.
- A second observer at the delivery point, calls when the marker travels past. This allows the control person to stop the counter, indicating the number of coal tracking section between load on and load off point.
- The accuracy of this method is dependent on reaction time of both the observers and the control person. The pre-warning stripe is a benefit.

9.1.4 On Load / Off Load Points Determination

Currently this has been determined by walking conveyors with a measuring wheel and determining lengths between different point in meters. This is not without error given steps and material spillage causing issues for accurate measurement. Slopes leading into trippers have also been neglected. It is anticipated that this measurement is sufficient for the coarseness of the material tracking philosophy. A more accurate method may be to use the technique in 9.1.3.

9.1.5 Flow Rate Sampling

Each section of material tracking, is based on the average flow rate over a weigher for that 10 meter section. The accuracy of the sampling is dependent on the number of samples taken. Typically 10 samples are taken. Improved accuracy could be achieved with more samples but PLC scan time will limit this.

9.1.6 PLC Scan Time

With all PLC control, it is important that the designer understands the nature of microprocessor based controls. Although fast, nothing occurs instantly, and each rung of code is scanned sequentially. Any measurement code needs to consider scan rate and where the operating code sits in the sequential scan. Time slicing and interrupt driven code can be used to improve a PLCs response and accuracy, but if high accuracy is required, it is better to use a dedicated piece of hardware for the function and then transfer the results to the PLC.

9.2 Small Flow Rate Discounting

Manual running of conveyors for checking, yard machine re-location and faster ramp up times is not permitted if any material is detected on the conveyor. Sources of small errors include wash down material, material that has hung in transfer chutes and then dropped, excessive water in the wet season and weigher zero errors. Through trial and error, a minimum value has been set to exclude from material tracking to ensure manual running without nuisance trips. This can create small errors in total tones on the conveyor, but as production tones are well above this figure, it was considered the best compromise.

9.3 Missed Tracking Pulses

Dependent on the speed rate from the pulse inputs and their duration, it may be possible for the PLC to miss counts. It is recommended that either high speed inputs or a dedicated pulse tracker be used to ensure that no pulse counts are missed. Typically issues may arise when a PLC has additional functionality added and the scan time is released. Designers need to be aware of the PLC scan time or events that may affect scan time.

9.4 Transfer Chute & PLC Comms Delays

There is a time lag for material to travel through transfer chutes. Currently this is not considered erroneous enough to be included in material tracking. Should an increase in accuracy be required, then this delay would need to be considered. $t = \sqrt{d/4.9}$ Where t = time in seconds and d = meters to fall.

There is also a delay in transfer rates between PLCs. Most modern PLCs have the option of Ethernet communications. At 100MHz on local managed networks, transfer rates under 250mS are easily achievable. This should be adequate for material tracking systems. If slower transfer rates are to be used, then the designer will be required to factor this into their error calculations.

9.5 Asynchronous Transfer Mismatch

No two material tracking "speed / section length" ratios are identical. This creates an asynchronous mismatch between individual sections when transferring from one conveyor to another. For example, if the ratio mismatch is 5% and the downstream conveyor's ratio is higher, then 1 in 20 sections will be missed. If the downstream conveyor's ratio is lower, then 1 in 20 sections will be read twice.

9.6 Checking Techniques

The most effective method of checking material tracking so far has been the use of ultrasonic pencils mounted above the conveyor to measure bed depth. Typically production material flows in full sections for optimum production, so a good bed depth is indicative of tones per hour.

9.7 Use in Virtual Weighers

Do not use material tracking weights to build virtual weighers! They will be too inaccurate for requirements. Virtual weighers should be built by tracking "weigher accumulated tones" (job or batch) through a separate tracking system from a known accurate weigher to their destination. This is the only method that will eliminate all of the errors mentioned above. This technique is currently used for the virtual weighers indicating batch and job tones loaded onto a ship. Note that it is self-correcting for missed pulses etc.