Index

North Sea FLOW Measurement Workshop

Paper 5.1

Allocation Computer Systems – Considerations for Vendors and Customers

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1 INTRODUCTION

Hydrocarbon allocation is a crucial activity for all operators and owners of oil and gas fields and production facilities. Allocation computer systems are used to automate the process and make it more accurate, timely and efficient. As the North Sea has matured, the demands placed on allocation systems have increased, firstly because shared infrastructure projects have become more common, necessitating commercial allocation of commingled fluids, and secondly because the emphasis on improving recovery requires accurate and timely reporting of production.

The authors have been developing and supporting allocation systems in the North Sea for the past ten years, and in that time have encountered certain common themes: that quantifying and achieving real business value is an elusive goal, that implementation projects are particularly prone to go awry, and that outcomes often vary significantly from what was anticipated.

However, while these appear to be common themes, analysis of the underlying causes is often based on subjective assessments and anecdotal evidence. There is a tendency to make general assumptions based on isolated experiences. When these assumptions and conclusions feed back into planning and procurement decisions for new projects, there is a risk that such decisions will be influenced too much by supposition and too little by hard facts.

Furthermore, the outcomes of allocation system projects are often not studied in detail. In advance of a project, here is a powerful incentive for both the customer and the vendor to define the expected benefits. Once a project is complete, however, the incentive to reflect on and quantify the *actual* benefits is much weaker. Yet that is exactly when the lessons can be learnt.

In an attempt to make an objective assessment of the success of allocation system projects, the authors conducted a study of recently completed projects. The study aimed to find answers to two key questions:

- How successfully do allocation systems achieve their objectives?
- What are the main factors that influence the success of such projects?

The definition and measurement of success in relation to IT systems is a subject of some debate in the academic literature (DeLone and McLean, 2003 [3]). Our approach was a simple qualitiative assessment of whether the business objectives, as stated in the business case or project sanction, were achieved.

1.1 Information Value-Chain

The context of allocation systems and their relationship to flow measurement can be understood in terms of an information value-chain, as represented in figure 1.

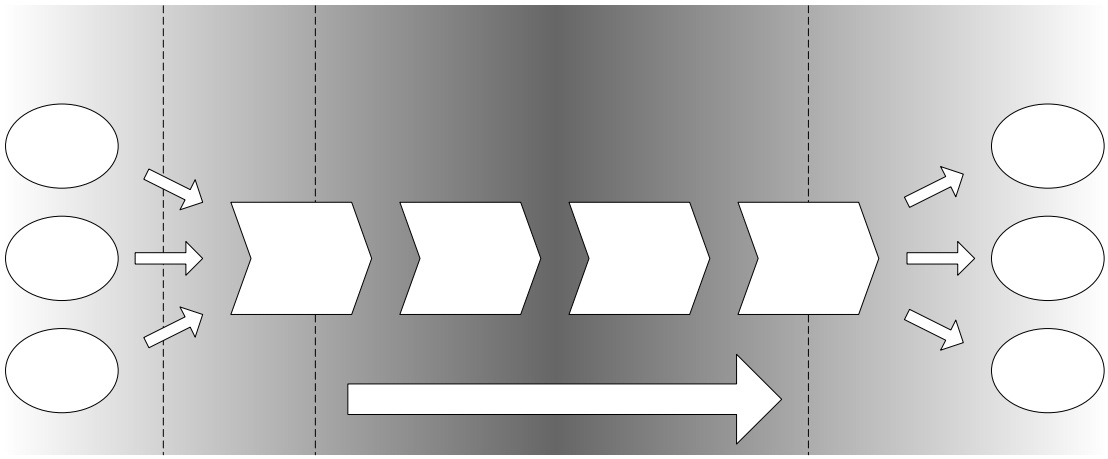

Fig. 1 – Information Value-Chain

In this model, information from flow metering systems feeds in at the start of the chain, and value is added incrementally as the information is processed in stages. At the end of the chain, high-value information is delivered to end users. For a typical allocation system, the processes in the chain include:

- Gathering data from multiple sources into a single database;
- Verifying data for completeness and correctness;
- Controlling changes to data due to mismeasurements and errors;
- Carrying out calculations to allocate measured flows to wells and fields (physical allocation);
- Applying commercial rules to attribute flows and stocks to owners, buyers and other parties (commercial allocation or attribution);
- Aggregating data for multiple assets and time periods;
- Presenting information to end-users and to other systems in the value-chain.

The information produced by this value-chain is used to generate reports for government (e.g. PPRS returns), allocation statements for joint venture partners, tariffs and invoices for shared-infrastructure users, and reserves statements.

Through consideration of this model, allocation systems can be defined as systems that convert flow measurements into definitive statements of production.

2 METHOD

In order to address the key questions posed above, a survey was made of recently completed allocation system projects. The survey focused on medium and large scale projects completed in the last three years which implemented new systems for North Sea assets. This type of project was of most interest because it involves significant choice in terms of product selection and implementation approach, and also carries significant risk. Data was gathered through questionnaires and structured interviews with project managers, sponsors and other personnel involved in implementing the projects. Participants gave information on the understanding that individuals, companies and projects would not be identified in this paper.

Data was gathered on the following aspects of the projects:

- Categorisation of project according to size, functional and asset coverage, type of solution and implementation method;
- Assessment of project performance against budget and timescales;
- Identification of details of the business case;

- Assessment of outcomes against the business case;
- Assessment of the impact of project management issues;
- Assessment of the impact of IT issues.

The sample included 16 projects, with an average budget of £820k. All the projects implemented solutions supplied by external software vendors (no in-house developments were included in the study). In all cases, there was a significant element of bespoke configuration, customisation and development to meet the customer's requirements.

Categorisation of projects by functional area is shown in figure 2, and by asset type in figure 3. These show the number of projects that implemented functionality in each category and for each type of asset. In all cases, a single project covered multiple functional areas and multiple asset types.

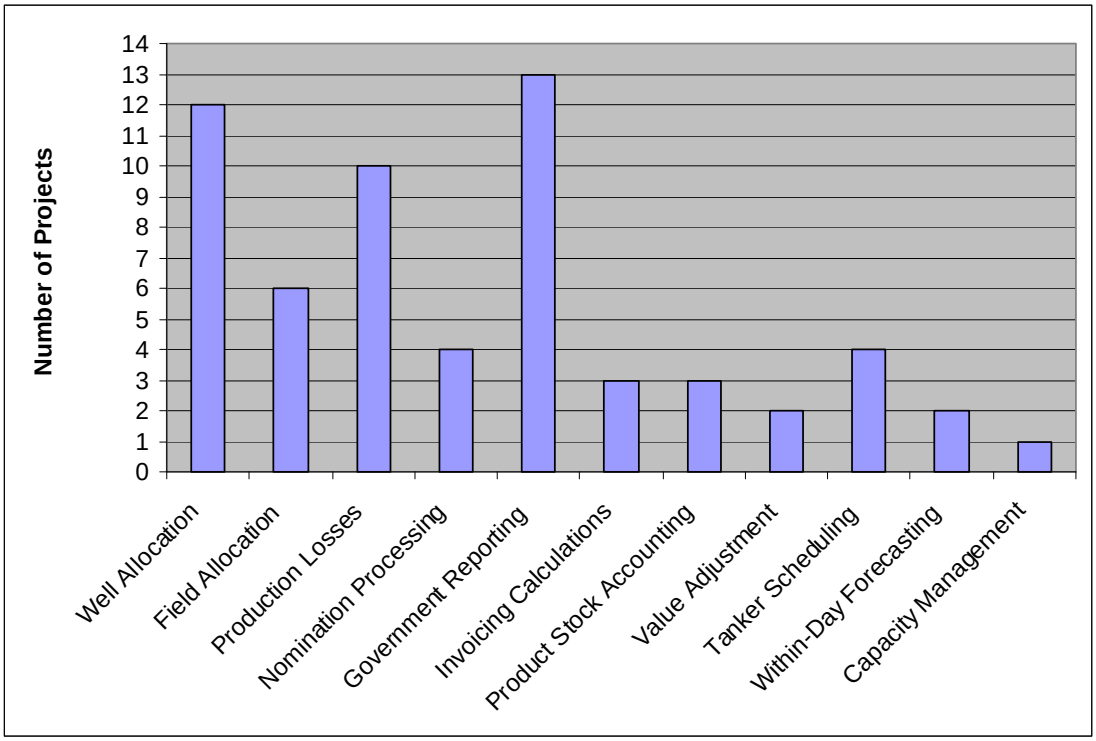

Fig. 2 – Categorisation of Projects by Functional Area

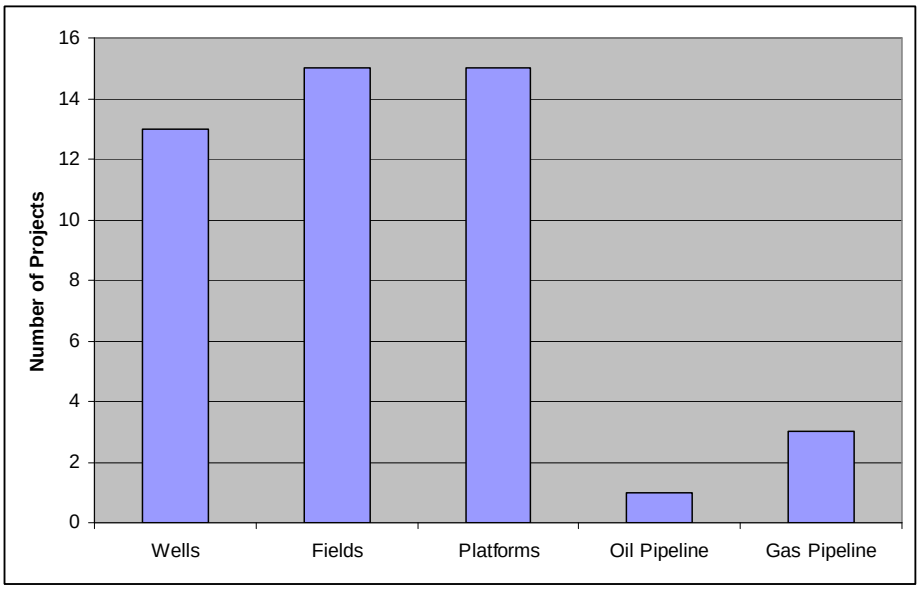

Fig. 3 – Categorisation of Projects by Asset Type

Analysis of the results was largely qualitative, as the sample was too small and varied for detailed statistical analysis. Quantitative analysis was performed where the availability of consistent numerical results made it possible.

3 ANALYSIS AND RESULTS

3.1 Achievement of Business Objectives

Business objectives were identified through reference to the business case, or where there was no documented business case available, the project sanction as understood by the study participant. We rationalised these into seven generic objectives (see table 1). We applied a grading of high, medium and low to the level of success for each objective, which combined the participants' assessment for each project with the number of projects for which that objective was achieved.

Overall, participants reported a high level of achievement of objectives. Few business case objectives were perceived not to be satisfactorily achieved. This observation should be considered in light of the fact that – almost exclusively – those surveyed had management responsibility for the projects in question.

Table 1 contains a summary of these results.

Table 1 – Summary of Achievement of Business Objectives

Objective	High	Medium	Low
Act as the definitive source of finalised production data	●		
Enforce standard business processes		●	
Control changes to data and provide traceability		●	
Implement well-defined and repeatable calculations	●		
Reduce/minimise cost of business process			●
Enable flexibility in the process		●	
Reduce exposure to business and financial risk		●	

The objectives with the highest level of success related to establishing the system as the definitive source of finalised production data, and implementing well-defined and repeatable calculations.

Those objectives rated as medium were generally achieved satisfactorily, but were assessed as less successful.

The objective that was least commonly achieved was cost reduction/minimisation. Relatively few projects included this objective in the business case. In those that did none succeeded in achieving the desired savings.

A significant issue concerning the business cases in the survey was the paucity of quantitative analysis. There was very little financial detail in any of the objectives, and very little attempt to quantify benefits in any rigorous way. Justification for projects was often based on necessity, or on vaguely defined business benefits.

3.2 Performance against Budget and Schedule

Participants were questioned on actual spend versus budget and actual duration versus schedule. Table 2 contains a summary of the performance of the projects against budget, and table 3 contains a summary of the performance against schedule.

Table 2 – Summary of Performance against Budget

Metric	
Number of projects surveyed	16
Number of projects under budget	1
Number of projects on budget	2
Number of projects over budget	13
Average (mean) budget	£820k
Average (mean) actual spend	£948k
Average (mean) percentage overspend	19%
Number with > 50% overspend	2

Table 3 – Summary of Performance against Schedule

Metric	
Number of projects surveyed	16
Number of projects under schedule	0
Number of projects on schedule	5
Number of projects over schedule	11
Average (mean) planned duration	8 months
Average (mean) actual duration	12 months
Average (mean) percentage overrun	35%
Number with > 50% overrun	3

The following factors were observed:

- A high proportion of projects overspent (81%) and overran (69%), while only one project reported an underspend and no projects were finished ahead of schedule.

- However, in most cases the overspend/overrun was relatively minor. Only two projects overspent by more than 50%, and three overran by more than this.
- The performance against schedule was, on average, worse than the performance against budget. There were two reasons for this: firstly there were a number of projects where progress slowed due to lack of available resource or rescheduling of work; secondly some fixed-price projects overran, but the increased costs to the vendor were not fully passed on.

3.3 Key Issues

The key issues affecting project outcome were identified through open questioning of the study participants, and assessed according to the participants' judgement. Project management and IT software issues were assessed separately. Across all the projects studied, the most commonly identified key issues were:

- Availability of suitable resources. Specifically: the lack of available staff among the project team who had sufficient business area knowledge; and the loss of staff with specialist knowledge part-way through a project. There was a very strong correlation between the overall success of the project and the reporting of resource availability as a key issue.

  This result is in line with previous studies into the factors affecting IT development projects generally, in which people issues have been shown to have more impact than any other factor, and productivity of individuals with similar levels of experience has been shown to vary by a ratio of at least 10 to 1 (McConnell p12 [2]).

- Implementation of project management processes. This issue is widely recognised as being important in preventing budget and schedule overrun and balancing the schedule/cost/scope trade-off. The worst performing projects in the study reported lack of good project management as a key issue.

- Contractual framework. This was an issue for fixed price projects that experienced cost and schedule overruns. In these cases, the contractual framework gave rise to a number of project management issues, including: a disincentive to consider any changes to requirements, even where they would bring clear business benefit; and an excessive amount of management time and effort spent on dealing with scope and contract issues, to the detriment of other aspects of the project. In the worst cases, these issues dominated management time.

One noteworthy finding was the fact that software product issues were not identified as key to project outcome in a negative sense for any project. Some relatively minor issues were reported, such as difficulties in integrating different software systems, and poor ease-of-use of certain products. However, fit between product functionality and business requirements was only reported in a positive light, as was the capacity to configure and customise products to match requirements. Where difficulties were experienced in delivering functionality, the ability of project staff to understand business requirements was a much more important factor contributing to the problem than the capabilities of the software.

4 CONCLUSIONS

The study described in this paper was a small, qualitative study focused on a highly specific area. There are limitations on the range and accuracy of conclusions that can be drawn from this type of study. However, as described in the previous section, a number of clear results emerged. In view of these results, what are the main considerations for vendors and customers involved in allocation system projects?

Firstly, while most projects overspend their budget and overrun their schedule, few get out of control. This would indicate that the view that this type of project is especially prone to becoming a disaster is an exaggeration.

Secondly, most business objectives are reported as being successfully achieved. However, it is apparent that certain objectives are more likely to be achieved than others. Establishing the allocation system as the definitive source of finalised production data, and implementing well-defined and repeatable calculations, are objectives with a relatively high chance of success. Achieving cost reductions through implementation of an allocation system is less likely. Also, most business objectives are not defined quantitatively, and therefore the level of success in achieving them cannot be assessed accurately.

Generally there is a lack of rigour in identifying benefits, and a lack of emphasis on achieving value from the investment. A common justification for projects is a simple one of necessity: the system is necessary for the business to function. The budget is then made up according to the cost of the preferred solution, and justified as being small in relation to the value of the business it enables. More rigorous analysis of value is often not carried out for this type of project.

Strong project sponsorship is key to successfully achieving business benefits. It can be of enormous assistance in driving standardisation and controlling complexity. A good project sponsor provides a high-level view which separates the important issues from the nice-to-haves. This can help to keep things simple and keep issues such as failures during acceptance testing in perspective. Without that kind of commitment, a project has to perform at a very high (perhaps unrealistically high) standard to build confidence.

Thirdly, the choice of contractual framework should be carefully considered, as it can have a powerful effect on the project outcome. A fixed price contract places a heavy burden on the requirements specification and on the vendor's estimates and project management practices. If the scope changes significantly, or if the contractor has difficulty in delivering against estimates, the management of the contract may become a major issue, often to the general detriment of the project. To the customer, the commonly accepted advantage of a fixed price contract is that it places the risk on the supplier. Theoretically, this makes the supplier less likely to take technical risks, and should prevent cost escalation. This orthodoxy presupposes certain behaviours on the part of the vendor and the customer. Vendors, for example, should track productivity, re-estimate frequently, and manage scope carefully. Customers should accept that they are ceding a degree of control over project resourcing, task prioritisation and eventual functionality. On both the vendor and the customer side, that presupposal is not always borne out and, consequently, this contractual model does not always provide the desired effect.

Finally, resource issues are a highly important factor in project success. The work required to implement an allocation system, and the nature of allocation itself, require specialist skills. The availability of resources with these skills is likely to determine the quality of the solution that is implemented.

Often, product selection is seen as the most important factor when initiating an allocation system project. It is common to spend many months and even years considering the suitability of available products and matching features to requirements in order to select the most appropriate software. In comparison, relatively little effort may be spent on selecting appropriate resources to carry out the implementation work. The fact that resource issues were identified, after project completion, as an important factor in project success indicates that these priorities should be carefully considered.

Problems with lack of suitable resources may not be immediately apparent on a project. An individual who lacks the capability to carry out a role effectively may still be self-confident and may spend a considerable time on the project before problems with productivity or quality are brought to the attention of management. Effective quality controls and decisive management are required to deal with such a situation.

The factors influencing success in IT projects have been widely considered and documented, for example by McConnell [2], Kuang et al [3], and in the Capability Maturity Model [1]. However, these refer to IT projects generally. Allocation systems differ from a typical IT application in the following ways, and therefore require special consideration.

- There can be a wide variation in requirements between different allocation systems, even for different assets within the same organisation. This is due to the widely differing configuration of assets and supporting systems, and particularly the detail of commercial agreements. Despite some efforts to standardise these areas, variation remains and has a major effect on the amount of bespoke configuration and customisation required to implement allocation systems. All the solutions in our study required a significant amount of work by system specialists to enable them to implement the business requirements.
- The esoteric nature of hydrocarbon allocation means there is a relatively small pool of IT resources with detailed knowledge of the area. Compared with business areas such as HR or logistics, allocation is more specialised and much less widely understood. The relatively small number of allocation system projects taking place, combined with the long time period required for IT resources to gain a good understanding of the business area, mean that this pool remains small.
- Allocation systems themselves tend to be complex, being based on large numbers of data points that can be difficult to distinguish between, and often involving extensive and complex calculations. This makes the software development and testing phases particularly prone to error

The successful implementation of an allocation system is undoubtedly a challenge. As with all IT projects, there is a risk of overrun and failure to achieve business objectives. The unique features of allocation systems call for careful consideration of the issues by both vendors and customers.

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North Sea FLOW Measurement Workshop

Paper 5.2

Flow Computers & Control Systems Interface or Integrate II

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Flow Computers and Control Systems Interface or Integrate II

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1 INTRODUCTION

At the 2004 North Sea Flow Measurement Workshop we presented a paper titled "Flow Computers and Control Systems Interface or Integrate". This paper assessed the overall suitability of the Honeywell Experion PKS (EPKS) system, as a representative Control System, for fiscal and allocation metering applications. The conclusion of the paper was that the required system functionality was available, the system was secure and reliable, and returned results that were accurate enough and ultimately when used in typical applications would result in a system with overall uncertainty limits within prescribed limits. The evaluation focused on gas orifice metering as this was considered to be the most complex application; the logic being that if the system was suitable for this application it should be suitable for all other metering applications – including liquid applications.

Late in 2004 and early 2005 Swinton Technology performed trials to evaluate the suitability of the Honeywell Experion PKS (EPKS) system, as a representative Control System, for liquid fiscal and allocation metering applications. Section two of this paper provides a brief overview of these trials.

Section three provides a summary of the integrated control systems and metering computer systems that have been implemented to date.

Swinton Technology has now implemented numerous metering computer systems using both the traditional flow computer systems architecture and integrated control system and metering systems architectures. The remainder of this paper compares the implementation of systems utilising these differing system architectures. Section four reviews the BP CATS metering computer system upgrade project using the traditional flow computer system architecture and includes significant feedback from both Mark Skelton and Mark Thompson – BP representatives on the project. Section five reviews the Petroplus Biodiesel system project using a control system for the metering computer system and includes significant feedback from Paul Adamson – Petroplus representative on the project. Section six provides a conclusion, highlighting pertinent points regarding the suitability of the differing architectures to meet the requirements of metering computer systems.

2 TRIALS TO ASSESS THE SUITABILITY OF CONTROL SYSTEMS TO IMPLEMENT LIQUID METERING SYSTEMS

A representative liquid turbine metering system was selected for the purpose of evaluating the suitability of the Honeywell Experion PKS (EPKS) system, as a representative Control System, for liquid fiscal and allocation metering applications utilising the following calculations:

- American Petroleum Institute Chapter 11.1, 1980 and 2004 to calculate temperature and pressure correction factors for generalised crude oils, refined products and lubricating oils
- American Petroleum Institute Chapter 11.2.1M 1980 to calculate compressibility factors for hydrocarbons
- American Petroleum Institute Chapter 12.2 1995 to calculate petroleum quantities using dynamic measurement methods and volume correction factors

As the conclusion of our previous paper was that the required system functionality was available, the system was secure and reliable, and returned results that were accurate enough and ultimately provided a system with overall acceptable uncertainty; the scope of

this trial was limited primarily to ensuring that the system could accurately perform the liquid specific calculations, appropriately handle the turbine meter dual pulse train and provide proving capability.

2.1 System Set Up

In order to evaluate the suitability of the control system, a typical liquid turbine metering system with the following instrumentation was simulated:

- Two liquid turbine meters – one per stream
- Five temperature transmitters – one per stream located downstream of the turbine meter, one on the inlet header and one on the inlet and outlet of the bi-directional prover
- Five pressure transmitters – one per stream located downstream of the turbine meter, one on the inlet header and one on the inlet and outlet of the bi-directional prover
- Nine motor operated valves – one inlet valve per stream, one outlet valve per stream, one prover off-take valve per stream, one prover inlet valve, one prover outlet valve and a prover four way valve
- Two densitometers located on the inlet header
- One bi-directional prover

2.2 EPKS System

The following system components were used to form the metering computer system for the trials:

- EPKS Server
- EPKS C200 Controller comprising the following cards:
    - CPU
    - Power Supply
    - Analogue input card – to measure pressure
    - PRT input card - to measure temperature
    - Pulse input card – to measure density and count pulses
    - Digital input card – to monitor valve positions
    - Digital output card – to control valve positions
- 2 off ST102 Dual Pulse Integrity Units – one per stream

2.3 Simulation

The following equipment was used to simulate the field signals and to enable relevant signals to be accurately measured.

- Pressurised pipe work with pressure transmitters to provide analogue input signals
- Calibrated Digital Volt Meter (DVM) to accurately determine the magnitude of the analogue input signals
- Calibrated resistance box to provide simulated PRT signals
- Pulse signal generator to provide a pulsed signal representing density
- Calibrated pulse counter (10^{-9} s) to accurately determine the period of the density pulse train
- Dual pulse signal generator to provide a pulsed signal representing turbine meter pulses
- Calibrated pulse counter to accurately determine the number of turbine meter dual pulses and the number of pulses during proving
- Digital input and digital output signal simulation to represent motor operated valves
- PLC to emulate the bi-directional prover including the four way valve and sphere switches
- Laser printer for alarm, event and report printing

2.4 Functionality

The additional functionality required by the liquid system, when compared with the previous gas system trials, was the ability to:

1. Accurately perform the liquid calculations
2. Appropriately handle the turbine meter dual pulse train
3. Prove the meter – including pulse gating, four way valve handling, prove sequence and error checking

New Customised Control Libraries were developed to perform the additional calculations. To verify that calculations had been correctly implemented. The calculations were verified against a third party calculation package and were all well within 0.001%.

The existing control system was already capable of counting pulses over the desired frequency range; however it was not able to perform dual pulse signal integrity checking. Consequently a Dual Pulse Integrity Unit was developed to perform level A dual pulse integrity checking in accordance with IP 252/76 Part XIII Fidelity and Security of Measurement – Data Transmission Systems, ISO 6551 Petroleum Liquids and Gases – Fidelity and Security of Dynamic Measurement – Cabled Transmission of Electronic and/or Electronic Pulsed Data and API Manual of Petroleum Measurement Standards, Chapter 5, Section 5 - Fidelity and Security of Flow Measurement Pulsed- Data Transmission Systems. The ST102 is a panel mount unit that operates in a manner similar to that adopted in many conventional flow computers in that the dual pulse trains are inputs to the unit with two pulse outputs (good pulse train and bad pulse train) which form inputs to the standard pulse input cards where the pulse counting is performed.

The Dual Pulse Integrity Unit also has a gated pulse train output that replicates the good pulse train output but is controlled / gated by further digital inputs that are connected to the prover detector switches. The gated pulse train is connected to a discrete channel of the pulse input cards to count the number of pulses during the prove run.

The prove sequence was implemented including the following:

- Automated diversion of flow through the prover loop
- Run control including half run and full run four way valve control and stability and credibility checks.
- Run repeatability calculations
- Final run average calculations
- Calculation of Meter Factor from Final Average K Factor and reference K Factor obtained from final average meter frequency and the frequency/K Factor look-up curve and production of associated reports
- Restoration of the proven stream to its normal state

The following error checks were implemented in the prove sequence:

- Failure of a run due to an excessive bad pulse count.
- Failure of a run due to a turbine meter line fault.
- Failure of a run due to a prover sphere sequence error.
- Failure of a run due to slow sphere travel.
- Failure of a run due to an end of run pulse count being well out of range.
- Failure of a run due to pressure or temperature deviations.
- Failure of a run due to excessive rate of change of a key variable.
- Failure of a run due to 4-way valve seal failure.
- Failure of a prove due to poor repeatability – cannot achieve five contiguous runs with acceptably small repeatability within the defined number of runs.
- Pausing of proving runs.

- Cancellation (aborting) of a proving run.
- Cancellation (aborting) of a proving session.

2.5 Overall System Accuracy

A test was performed in order to determine the overall accuracy of the entire metering computer system; i.e. this was not a simple totalisation test, it was a full system error test.

This test involved simulating system input signals, noting both the simulated signals using high accuracy and calibrated measuring equipment and those values returned by the control system as the measured values, then keypad entering the control system measured values into the control system and allowing the system to run for a period of time.

The resultant totals from the control system were then compared with those returned from a third party verification package which had the noted values returned by the high accuracy and calibrated measuring equipment keypad entered into it. The resultant errors in totals, taking into account all I/O and calculation errors were within prescribed limits; e.g. the error associated with gross volume total was -0.000714%.

It was concluded that the metering computer system had minimal effect on overall system uncertainty and the associated accuracy was such that it was suitable for both custody transfer and allocation metering applications.

The values detailed above can be reduced further through the use of digital transmitters as this negates the requirement, and hence the associated uncertainty, to convert the digital signals to analogue signals within the transmitters and then to measure the analogue signal at the metering computer system in order to convert it back into a digital value.

3 CONTROL SYSTEM METERING COMPUTER SYSTEMS IMPLEMENTED TO DATE

Detailed below is a table summarising the metering computer systems that have been implemented by Swinton Technology using control systems:

Table 2: Metering Computer Systems Implemented To Date Using Control Systems

Project Name	Location	Meter Types	Delivered
Shell North Cormorant	UK Offshore	Orifice plate	July 2005
Petroplus Bio-Diesel	UK Onshore	PD and Coriolis	November 2005
Petroplus Jet Fuel	UK Onshore	PD	November 2006
Marathon Enoch	UK Offshore	Ultrasonic, v-cone, turbine and orifice plate	March 2007
Marathon Brae B	UK Offshore	Orifice plate	November 2006
Isle Of Grain	UK Onshore	Ultrasonic and Coriolis	October 2007
Triton OSPAR	UK Offshore	Ultrasonic and v-cone	November 2006
NCRA Conway Terminal	America Onshore	PD	November 2006
Woodside	Australia Onshore	Orifice plate, turbine and Coriolis	May 2008

During this same period Swinton Technology delivered 21 metering computer systems using the traditional flow computer systems architecture.

4 CENTRAL AREA TRANSMISSION SYSTEM FLOW COMPUTER UPGRADE PROJECT

4.1 CATS Terminal Overview

The CATS system is operated by BP and comprises of an offshore riser, pipeline and an onshore terminal. CATS offers a transportation and processing facility for customers seeking to develop their gas reserves. The system can handle more than 1.7 billion cubic feet of natural gas per day, enough gas to supply 20% of UK demand, and has the potential to expand this capacity.

CATS begins at the riser platform adjacent to the Everest gas field in the Central North Sea. Gas is transported through the CATS pipeline some 250 miles to the processing Terminal at Seal Sands, Teesside. CATS is the only natural gas transportation system to bring gas from offshore fields directly into a major industrial area in the UK.

CATS pipeline comes ashore at Coatham Sands, south of the River Tees, from where it runs for 5 miles below ground to the CATS Terminal. The Terminal, situated on a 72-acre site, contains processing facilities that clean the incoming gas as well as removing natural gas Liquids (NGLs). Cleaned natural gas is metered and odourised before being exported to the National Transmission System (NTS) and third parties. NGLs are fractionated into useable liquid products including Propane, Butane and Pentanes plus – these liquids are fiscally metered prior to being exported to third parties.

4.2 Project Overview

This primary focus of this project was to upgrade the existing CATS metering computer system as the flow computers and the Metering Supervisory Computer (MSC) were obsolete, the system was proving increasingly difficult to maintain and associated failures had resulted in lost production.

BP's Capital Value Process (CVP) was adopted by the Project Team as the project was considered to be business critical. The CVP process requires the project to run through a series of clearly defined stages (Appraise, Select, Define, Execute and Operate) where appropriate personnel review and approve the project at the "gates" between each stage.

BP recognised from the outset that it was necessary for the new system supplier and those involved representing BP to have a detailed understanding of metering computer systems and in particular upgrading such systems. BP elected to manage the project themselves rather than utilising an external engineering company or Consultant company. It was recognised that by adopting this approach their would be an increasing reliance on the new system supplier to obtain relevant site data / information as the BP staff managing the project would not have time available to do so, as they were still having to perform their usual duties.

During the Design stage of the project the most appropriate architecture of the system was considered and the traditional flow computer system approach was considered to be more appropriate than a control system architecture as:

- At the time the use of control systems for such functionality was a new approach and had not been tried and tested.
- The existing system three layer architecture (flow computer / MSC / Allocation System) was considered to provide high levels of redundancy and the availability of an associated control system for this duty was not known.
- There was a preference to keep the metering system separate from the control system.
- The only control system available that could provide the required functionality differed from the existing site control system.

Key concerns identified by the team at the start of the project were:

- The fact that a live changeover was required as the terminal only shuts down every seven years, and during the changeover it would be necessary to maintain numerous system interfaces – communication links and hardwired signals.
- There were a number of areas of functionality of the existing system where the associated site knowledge was somewhat limited and this needed to be resolved in order to implement the new system.
- It was essential that the new system was protected from computer viruses.

The system upgrade included the replacement of:

- The flow computers associated with three pipeline metering stations, one sales gas station and three liquid stations – 21 flow computers in total. FloBoss S600 flow computers were supplied.
- The dual MSC – A HP DL380 Cluster MSC was supplied.
- Three PLC's – two Allen Bradley SLC 500 PLC's were supplied.
- Five chromatograph controllers – Daniel 2350A chromatograph controllers were supplied.
- Chromatograph – A Daniel 591 C1 – C10 dual sample stream unit was supplied.
- Workstations
- Printers
- Some of the field transmitters.

The new system replaced the existing system and also provided a suite of integrated metering management software including KIMS® (instrument management system), K-TRAC® (meter proving software), K-View® (real time graphical data logging) and K-Log ® (electronic logbook) using the FM^2P® package that enables the MSC and the individual management software components to automatically share data which ensures accuracy of data and reduces the engineering time required to perform the associated metering management tasks.

An Overview of the replacement system supplied is detailed overleaf:

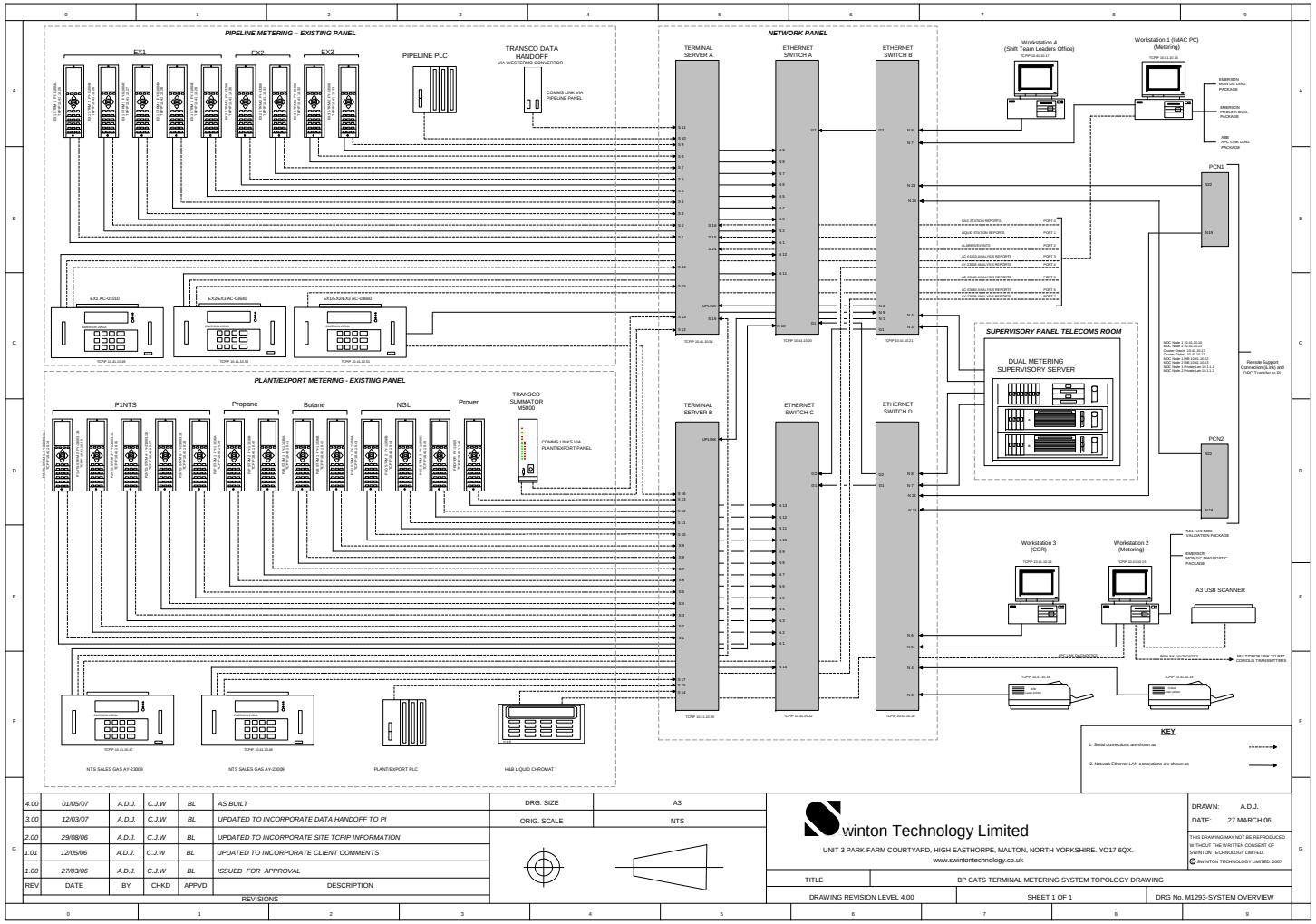

Figure 1 : BP CATS Terminal Metering System Upgrade Project System Overview Drawing

4.3 Project Implementation Challenges

Detailed below is a summary of the key challenges encountered during the implementation of the project:

It was necessary to extend the site survey in order to ascertain in detail the functionality of the existing system in a number of areas associated with metering system database configuration and host interfaces. In order to establish some of the existing system functionality it was necessary to review line by line the existing system software code.

The system design needed to account for the fact that the system had to be installed and commissioned when the system was still in operation – including maintaining a number of third party interfaces during the changeover.

- The spare FloBoss S600 was used temporarily during the changeover to maintain the analogue output and pulse output signals to Transco. This was achieved by taking the relevant signals from the existing system and the signals form the new system and producing relevant outputs that represented the sum of the new and the old system signals.
- The system needed to provide the Operator with P1NTS nomination data. The existing system communicated relevant data to the PI system and this data was then communicated to the new MSC which calculated and displayed the station required nomination data.
- The allocation system was revised to receive data from both the existing and the new system and to sum this data together in order to create station data. The existing system interface was turned off when the relevant flow rates became zero; i.e. when the relevant streams had been changed over from the existing system to the new system.

The panel upgrade approach detailed in the initial Request For Quotation (RFQ) was to supply new panels located in front of the existing panels; this would reduce the space in the control room but was considered appropriate to facilitate the required live changeover. During detailed design development it was established that by temporarily relocating some of the equipment (flow computers, chromatograph controllers, test panels and fans) and developing a standard flow computer interfacing kit for CATS, considerable panel space was saved that enabled the rapid transfer of signals from the existing system to the new system. This meant that the existing panels could be utilised without the requirement for new panels in front of the existing panels. It was decided to supply some additional appropriately prepared panels to sit alongside the existing panels to allow for future expansion as it was anticipated that expansion may be required in the near future.

The site survey and detailed design stage identified that the existing PLCs were obsolete and hence it was decided that it would be wise to replace them.

BP operates with three discrete communication networks – firewalls are used to bridge across the differing networks. The MSC resides on one LAAN whilst the PI and allocation systems reside on other LANS. Prior to the MSC being allowed to be used on the BP LAN's, the system needed to be scrutinised by BP's IT Department – as part of this process it was necessary to complete a detailed document (Technical Infrastructure Plan) regarding the system for BP's reviewing purposes.

4.4 Project Installation And Commissioning Challenges

Detailed below is a summary of the key challenges encountered during the installation and commissioning of the project:

A problem was encountered with the pulse signals from the Coriolis meters at higher flowrates / pulse frequencies. The problem occurred as a result of a requirement for an alternative resistor network arrangement due to electronic signal level differences between the Micro 5000 and FloBoss S600 flow computers.

There were initial communication problems encountered between the PI system and the MSC. The problem arose as the firewall between the PCN and PIN has not been configured to allow data to pass between the two systems.

A problem was encountered with the FloBoss S600 differential pressure mode handing in that when conventional 4 – 20 mA signals are used the mode handling tasks deems the signal to have failed when it falls below 3.5mA; however when HART is being used the signal was deemed to have failed at 4.0 mA. The consequence of this was that the MSC was receiving vast quantities of data when streams were off-line. The issue was resolved by writing alternative differential pressure mode handling using the FloBoss S600 logical calculation tools.

Following the installation and commissioning phase BP requested that McAfee anti-virus software was installed on the MSC; however when this was installed it caused the system to crash. Following investigation it was identified that the anti-virus software was failing and causing the system to crash. The problem was resolved by installing a later version of McAfee anti-virus software.

The system calculations and functionality have now been successfully audited by Department of Trade and Industry, Norwegian Petroleum Directorate and Transco.

Recently it became necessary to revise the flow computer software to include the ISO 5167 Joule Thompson correction. To effect this change the flow computer software was changed at Swinton Technology works and a subsequent client witnessed test of the revised flow computers took place; prior to the software being updated on the site machines.

Recently the system was expanded to include a new dual stream Fuel Gas S600. This flow computer was fitted into one of the new panels that was supplied to accommodate potential future expansion.

5 PETROPLUS BIO DIESEL CONTROL SYSTEM PROJECT

5.1 Petroplus Teeside Refinery Overview

The Petroplus Teeside Refinery is located on a 40 hectare site on the northern coast of England. The refinery is focused on straight run distillation with a name plate capacity of 117,000 barrels per day.

A key strength of the refinery is the ability to produce low sulfur diesel that already meets the E.U. 2009 mandatory maximum 10ppm sulfur limit for gasoline and diesel. The refinery supplies approximately 17% of all commercial diesel demand in the UK.

Through an agreement with a biodiesel additive producer, the refinery currently supplies the majority of the United Kingdom's biodiesel blend, branded as Bio-plus. Bio-plus is a 95% : 5% blend of mineral oil diesel with methyl ester derived from renewable sources such as rapeseed, palm oil, soya or used cooking oil.

5.2 Project Overview

In 2005 Petroplus Teeside Refinery expanded its portfolio to supply Biodiesel, by buying in Fatty Acid Methyl Ester (FAME) and blending this with Ultra Low Sulphur Diesel (ULSD) produced at the refinery.

The FAME was delivered by road tankers and held in storage tanks at the road rail terminal.

The ULSD was produced at the Refinery, located three kilometres from the road / rail terminal, and pumped to the road / rail terminal where it was blended and held in storage tanks prior to being transported to customers by means of road or rail tankers.

It was necessary to accurately measure the FAME delivered by the local supplier prior to the product being stored in a local storage tanks - two PD meters were used for this duty in a two off 100% stream arrangement.

It was necessary to accurately measure the ULSD and FAME being blended prior to it being held in road / rail storage tanks. Each product was measured by two PD meters in a two off 100% stream arrangement; however in addition a Coriolis meter was used as a check meter to also measure the FAME.

The allowable tolerance of the blend was between 3.5% and 5.0%; however the associated business case had been developed based upon a blend of 4.25% FAME.

A summary of the requirements of the required new control system located at the road / rail terminal are detailed below:

1. Measure the FAME arriving at the road / rail terminal to fiscal standards
2. Measure the FAME being blended to fiscal standards
3. Measure the ULSD being blended to fiscal standards
4. Control the ULSD pumps at the Refinery via the existing Honeywell TDC 3000 DCS
5. Control the FAME pumps – automatic start and stop based upon the ULSD flow rate
6. Control the level in the FAME storage tanks
7. Control the level in the Biodiesel storage tanks
8. Accurately control the blending of the FAME and ULSD by means of flow control valves
9. Automated system shutdown in the event of the blend mixture being outside of prescribed limits
10. Automated system shutdown in the event of specified alarm conditions
11. User interface to be Abnormal Situation Management (ASM) compliant

As the project required both a fiscal standard metering computer system and advanced control, Petroplus elected to extend their existing DCS (TDC 3000) functionality to provide the desired functionality rather than procure a separate metering computer system and either a new control system or extend the existing DCS system for the control functionality.

A robust and reliable system was required as the consequences of adding either too much or too little FAME could result in a tank being outside of the agreed tolerance limits. Consequently a system was ordered with redundant servers, redundant controllers and redundant I/O utilising the site standard I/O modules.

The government regulator covering the refinery is Her Majesty Customs and Excise (HMCE). The new system therefore needed to be complaint with HMC&E Notice 179 - Motor and Heating Fuels: General Information and Accounting for Excise Duty and VAT.

The system comprised of:

- A single bay panel located at the road / rail terminal containing:
  - Redundant C200 controllers
  - Redundant C200 I/O racks – each containing two pulse input cards
  - Two PMIO I/O racks – containing two analogue input cards, two analogue output cards, one digital input card and one digital output card
  - Seven ST102 Dual Pulse Integrity Units
  - Two network switches
  - Redundant 24V DC power supplies

- Operator workstation located in the road / rail control room
- Redundant servers at the road / rail terminal
- Redundant servers located at the refinery
- Two network switches located at the refinery

A system block diagram of the system supplied is detailed below:

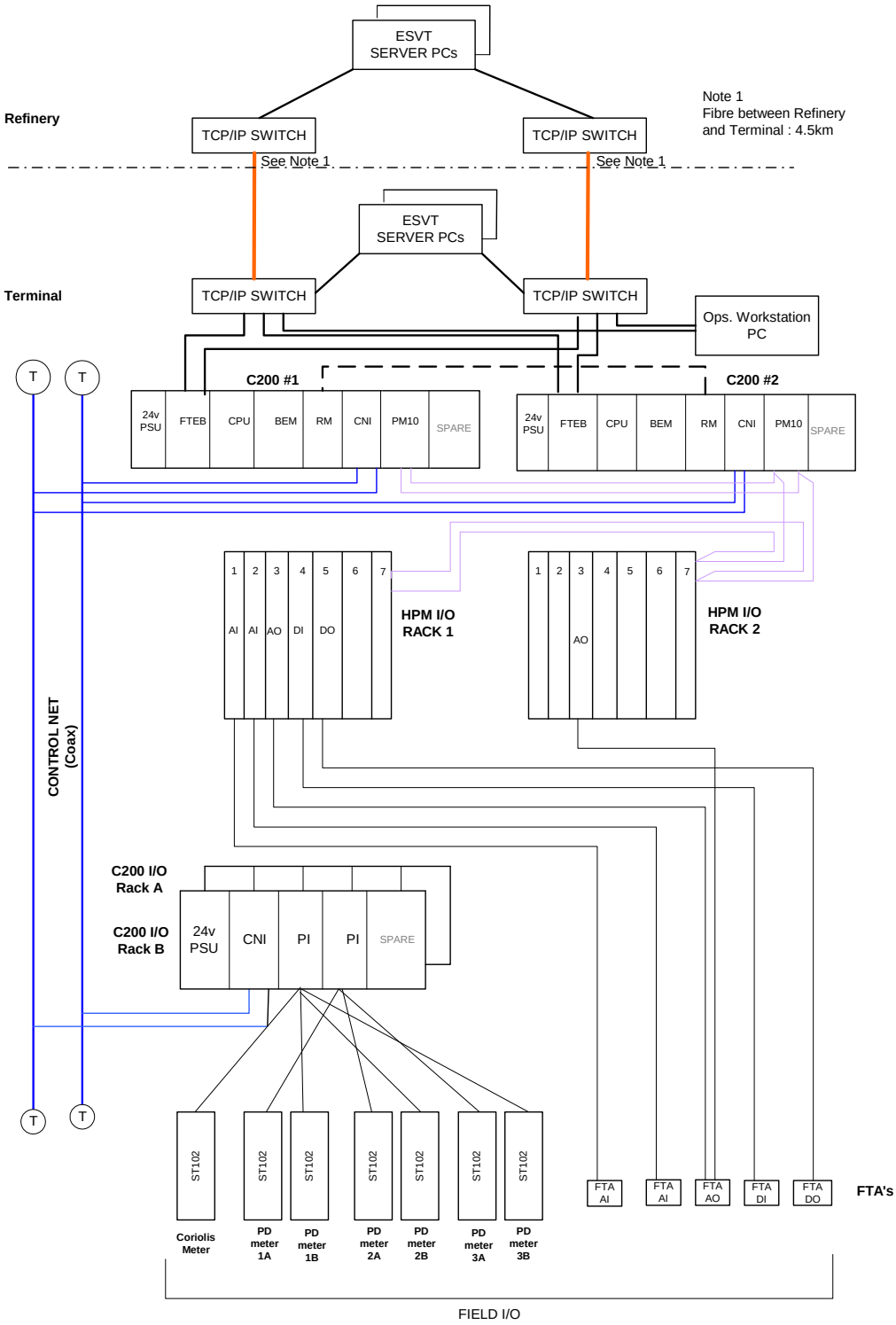

Figure 2 : Petroplus Teeside Refinery Biodiesel Metering and Control System Overview

5.3 Project Implementation Challenges

Detailed below is a summary of the key challenges encountered during the implementation of the project:

The project was deemed to be a “fast track” project as at the time of order placement there was little time to implement the system prior to the date on which Petroplus were contracted to procure FAME from a local supplier and Petroplus would incur penalties if they were unable to accept the product on this date.

The project required both advanced control and metering within the same controllers and hence there was a requirement for Honeywell engineers and Swinton Technology engineers to work closely together during the implementation of the system. This challenge was addressed by the engineers, including the site resident Honeywell engineers, working as a single team located at Swinton Technology works prior to the Factory Acceptance Test.

Following the Control Hazards and Operability Analysis (CHAZOP) review it was decided that servers should be available at the road / rail terminal to ensure safe operation in the event of failure of the refinery / road rail terminal communications link. Hence the project scope was increased to provide the additional servers at the road / rail terminal.

The new system needed to provide control and metering at the road / rail terminal and also needed to provide control at the refinery via the existing TDC 3000 DCS. Communication between the new system and the existing DCS was very simply achieved using Distributed Systems Architecture (DSA) technology to communicate between the Experion Servers and OPC Integrator that was specifically designed to seamlessly integrate between the current Experion DCS technology and the TDC 3000 DCS technology.

The day before the Factory Acceptance Test (FAT), Petroplus advised that the control philosophy that they had requested in relation to control of the pumps and flow control valves needed to be revised. Consequently the associated configuration needed to be revised and retested prior to the start of the FAT.

5.4 Project Installation And Commissioning Challenges

The primary problems encountered during the installation and commissioning were in relation to the dual pulse signals from the PD meters. As this was the first liquid control system metering computer system project it was the first project where the ST102 Dual Pulse Integrity Unit had been used in earnest and hence when problems were identified with the meter pulses it was initially suspected that the problem was caused by an error with the ST102. The ST102 was not at fault and there were two reasons why these problems were encountered:

- The field cabling installed for the meter signals was inappropriate – it was not twisted pair cable with each pair individually shielded
- The meter PCB’s did not have a conformal coating and were encountering problems as the PCB’s were in damp enclosures

The pulse issues were rectified by installing the correct field cable and rectifying the meter PCB’s.

Apart from the pulse issue detailed above and the very short timescales available, compounded by the need to delay the commissioning to run in the new field cable, there were very few problems encountered during the installation and commissioning phase of the project.

Having the site resident Honeywell engineers involved in the project helped during the implementation stage, installation and commissioning phase and post commissioning phase of the project as they brought site knowledge to the project team during the implementation stage and had intimate knowledge of the new system when it arrived on site.

Petroplus confidence in the metering and control system is such that the blending set point is set at 4.999%; almost 0.75% greater than that detailed in the initial project business case. This difference in set point provides Petroplus with significant commercial benefit as the product is blended within specification with a higher percentage of the lower cost FAME.

The system has been successfully audited by HMC&E.

Recently a further MeterSuite system has been installed at the road / rail terminal as part of a Jet Fuel Truck Loading system.

6 CONCLUSIONS

Detailed below are a number of conclusions regarding the most appropriate approach, traditional metering computer systems or control systems, to provide metering computer system functionality:

1. Although control systems now include the metering calculations required for most applications, and the list of available calculations is increasing with time, the range of metering calculations available in the market leading flow computers is more comprehensive than those currently available in control systems.

2. Some of the market leading flow computers are very flexible through the use of their configuration tools; however with traditional flow computer systems the associated supervisory computers are less flexible and hence with a traditional flow computer based system it is often necessary for the original metering computer system supplier to make even minor modifications. With control systems there is a greater level of flexibility available through configuration tools; hence providing users with the option of making changes themselves – in particular batch and sequencing changes can be simply revised with control systems.

3. Connectivity in a metering computer system can be deemed to be split into two – field transmitter connectivity (Hart, Fieldbus, Profibus etc.) and higher level system connectivity (SCADA / DCS, ERP systems etc.). Flow computers do not have the same level of field transmitter connectivity as control systems; however metering supervisory computers typically have a number of connectivity options available as do control systems. Where the metering computer system needs to communicate with a control system the associated implementation is far simpler when the same technology is utilised for the metering computer system as the control system, in many cases seamless integration can be achieved which can provide significant benefits both during the implementation of the initial project and also in the future as system requirements change.

4. Many customers and metering computer system integrators consider that when you are upgrading metering computer systems that you have to replace the existing panel. Providing that the existing panel is in good condition it is often possible to retain the existing panel and by performing off-site engineering (e.g. development of standard interface sub-assemblies) significantly reduce the associated upgrade project cost, project risk, installation and commissioning time and system down time. When upgrading a flow computer based metering system where the existing panel is retained, the simplest approach is often to replace existing flow computers with direct replacement flow computers, rather than installing a new control system, as this minimises the required panel changes.

5. Many customers have a strong preference to keep their metering computer systems separate from their control systems and perceive that if control system technology is used to provide the metering control system functionality they cannot segregate the metering computer system from the control system. This is not the case as even when utilising a single technology for both duties the systems can be segregated by simply using discrete controllers, and servers if necessary, for the metering computers system functionality.

6. Traditionally when metering computer system functionality is revised a customer witness test takes place with a representative system covering the revised functionality. Many systems, in particular when computers are supplied running Microsoft operating systems, require periodic software updates as a consequence of operating system obsolescence, operating system fixes and general system fixes. With traditional metering computer systems the general approach is to build a representative system containing the appropriate components and perform associated testing prior to installing the revised software. With control systems the approach in general is quite different in that prior to revised software being released it is comprehensively tested by the control system supplier prior to release and in many cases the software is updated without customer witnessed testing taking place prior to installation. The general control system approach is not adopted as a less stringent approach; not surprisingly as many control systems are used to control business critical and extremely high value plant operations – it is just an alternative approach adopted within a different business sector. In order to satisfy customers, when control systems are used as the metering computer system and functionality changes are implemented, Swinton Technology set up a representative system and hold a customer witnessed test; however generic system testing is performed covering metering calculations and totalisation tests when either operating system or general system fixes are implemented.

7. Control systems are now scalable and hence can be cost effective from a low number of streams.

8. Plant wide DCS systems are typically large control systems that cost significantly more than a metering computer system and consequently end users expect them to have a long life span; typically in excess of twenty years. Traditional flow computer based metering computer systems are far less expensive and end users expect them to have a far shorter life span; typically seven to ten years; e.g. CATS anticipate that their system will have a life span of ten years.. Hence where sites have an anticipated life span in excess of ten years the use of control systems to provide the metering computer system functionality is likely to lead to lower life cycle costs.

9. The use of control systems to provide metering computer system functionality was a new concept at the turn of the millennium, and was still fairly new when the CATS RFQ was raised, but it is now a tried and tested approach. However there are still many end users who still consider the traditional flow computer based system to be the approach that they should adopt for their metering computer systems – we should not be too surprised by this as the metering community is in general very conservative.

10. Where a site has a requirement for a new or replacement metering computer system at the same time as a new control system, or needs to interface with an existing control system, there are significant benefits associated with procuring a single control system or extending the existing control system to include the metering computer system; rather than installing a flow computer based system for this duty. This approach can only be adopted however where the control system is able to provide the required functionality.

11. The functionality available in control systems is extensive and continues to increase day by day. It is envisaged that in the future benefits will be realised by combining the metering computer system functionality within the control system and the wide range of functionality already available within the control system. Improved plant optimisation through greater data accessibility and advanced system control techniques is such an example.

North Sea FLOW Measurement Workshop

Paper 5.3

Features of Allocation Systems Incorporating Long Pipelines

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TÜV SÜD

nel technology for life

Features of Allocation Systems Incorporating Long Pipelines

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1 INTRODUCTION

There are two main approaches to systems of allocation that include long pipelines. The first accounts for each user's hydrocarbons within the pipeline itself. The second method ignores the transit time in the pipeline and allocates the metered quantities exiting the pipeline based on the metered quantities input into the pipeline on the same day; using this approach parties will not be allocated precisely what they input to the pipeline on a day, but over a period of time there is an expectation that any daily gains and losses will even themselves out.

This paper examines instances when this is not necessarily true depending on the allocation equations employed. It demonstrates, using simple models and results from a real allocation system, how parties can be systematically under and over allocated hydrocarbons due to the mathematics of the allocation agreement. It goes on to examine the reasons for this unexpected and subtle bias in the allocation system and presents methods to assess the stability of the equations and approaches to eliminate allocation bias.

It also discusses the wider implications for allocation systems in general, particularly in terms of how the assumptions, equations and logic of a system should be tested at the conceptual development stage to prevent problems occurring.

In Section 2 a simple model is used to describe an allocation system associated with a pipeline. This model illustrates the basic process and presents the main features of the allocation methodology. Data from an analogous real system is presented to highlight a problem with the allocation results of such a system. In Section 3 the model is then used to analyse the allocation system behaviour without the obfuscating effects of measurement uncertainty in the real data.

2 PIPELINE ALLOCATION SYSTEM DESCRIPTION

A simple system incorporating a long pipeline is presented below and this is used as a basis to describe allocation issues associated with a real system.

2.1 Process Description

Consider two offshore platforms exporting gas to an onshore gas plant via a long pipeline such as that presented in Figure 1 below:

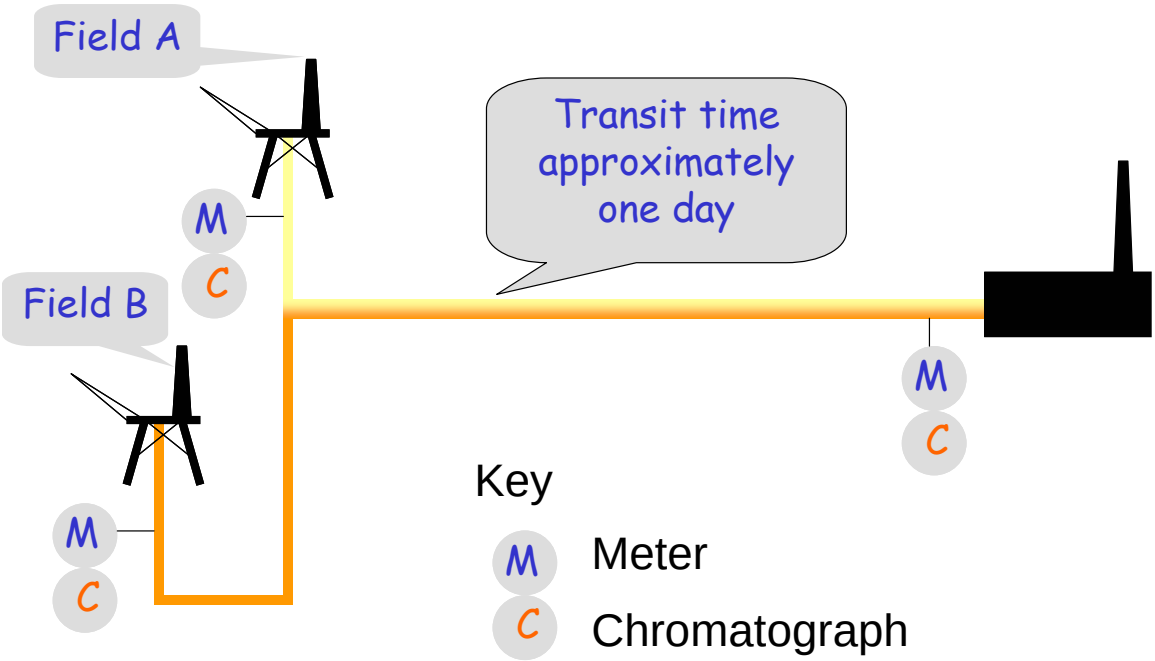


Figure 1 – Process Schematic of Two Platforms Delivering Gas to an Onshore Gas Plant via a Long Pipeline

Gas from Fields A and B is exported from two offshore platforms into a subsea pipeline where the gases are commingled and delivered to the inlet of an onshore gas plant. The two Fields' gases are of differing compositions and are continuously metered offshore and the composition determined by on-line chromatographs. Similarly the gas plant inlet flow is metered and the composition measured.

The pipeline is deemed long in that it takes approximately one day for the gas exported offshore to arrive onshore. The consequence of this is that the gas arriving onshore "today" was in fact exported "yesterday". If the composition or flow of either, or both, Field's export varies from day to day (as is almost certainly the case) then the gas metered and allocated at the inlet will have a different composition to the combined platform export on an allocation day.

2.2 Allocation Methodology

Typically in such systems the gas delivered to the Gas Plant is processed and exported into a transmission pipeline system and delivered to end users. Buyers of the gas nominate quantities on a day and the Fields export gas from the platforms in response to these nominations. Hence, in order to meet nominations, the quantity of gas displaced from the pipeline through the plant inlet will be roughly equal to the combined export on a day. In order for the Fields to meet their buyer's nominations, this inlet gas will normally be allocated in proportion to the Field exports. However as stated above this inlet gas will almost inevitably be of different composition to that of the combined export.

In this particular system, the gas is allocated on mass component basis and the allocation system is built on the premise of preserving a mass balance at component level. This means that whatever a Field exports at a mass component level, it should ultimately be allocated an equivalent quantity in terms of gas plant products, i.e. gas export, fuel gas, NGLs, etc. Any differences on a day are reflected in changes to the pipeline stock.

A simple scheme, and at first sight perhaps the most obvious and intuitive, is to allocate the inlet gas, at a component level, in proportion to the quantity of that component the respective Fields exported on the same day. This is illustrated with a simple numerical example in Table 1:

Table 1 Metered and Allocated Quantities

	Field A	Field B	Inlet
Metered	10	20	33
Allocated	11	22	33
Stock Change	-1	-2	

These figures could pertain to any component and be on a mass or molar basis – since mass and molar quantities are conserved across the pipeline. For illustrative purposes it will be deemed that the above quantities refer to C1 (methane) and are in mass units.

Since it takes roughly one day for the gas to pass through the pipeline the gas being allocated at the gas plant inlet is effectively the previous day's export gas but it is being allocated based on today's export gas quantities. Slightly more mass of C1 is metered at the inlet than is exported offshore on that day and this is simply due to the fact that there was a different commingled composition exported the previous day.

In order to preserve the component mass balance the difference between what a Field exported and what it was allocated at the inlet is accounted for by a change in the pipeline stock allocated to that Field. The pipeline stock change is calculated as the difference between the allocated inlet and offshore export quantities. The stock change for both Fields in the example is negative indicating more of that component has been removed from the pipeline than has been exported into it that day. The next day the figures could be positive varying in accordance with the fluctuations in offshore export flows and compositions.

Each Field has a total pipeline stock which represents the cumulative difference between what it has exported and what it has been allocated at the inlet. The total pipeline stock, i.e. the sum of the two Fields, represents the physical contents of the pipeline. The daily stock change is added or subtracted from each Field's previous day closing balance to obtain a new closing balance of pipeline stock.

The above is expressed in equation format below. The allocated inlet to Field A is given by:

$$AI_{A,c} = \mathrm{M}I \times xI_{\mathrm{c}} \left[\frac{\mathrm{M}E_{\mathrm{A}} \times \left(xE_{\mathrm{A,c}}\right)}{\mathrm{M}E_{\mathrm{A}} \times \left(xE_{\mathrm{A,c}}\right) + \mathrm{M}E_{\mathrm{B}} \times \left(xE_{\mathrm{B,c}}\right)} \right] \tag{1}$$

The change in stock by:

$$\Delta S_{A,c} = \mathrm{M}E_{\mathrm{A}} \times \left(xE_{\mathrm{A,c}}\right) - AI_{A,c} \tag{2}$$

And the new closing stock by:

$$SC_{A,c} = SO_{A,c} + \Delta S_{A,c} \tag{3}$$

The closing stock becomes the opening stock for the next day. Similar equations can be written for Field B.

Though a Field may be allocated more or less of a component at the inlet than it exported on a day, reflected in a positive or negative stock change, it might be expected that these gains and losses would even themselves out over a period of time. The assumption that "you get out what you put in" over a period of time appears intuitive and at first sight reasonable.

The above equations are simple but it should be noted that they are non-linear. Also the fact that the length of the pipeline introduces a time factor implicitly into the calculations means that the equations are also dynamic in nature. Such systems of simple non-linear, dynamic equations have been found to behave unexpectedly and exhibit instability. In fact there is

now a whole field of mathematics and engineering concerned with the nature of stability and chaos associated with such equations [1]. With this in mind it is perhaps not surprising that unexpected results may follow from the allocation equations presented above.

2.3 Allocated Pipeline Stock Problem

Table 2 presents allocated pipeline stock data from a real allocation system* that operates in a similar manner to the simple system described in Sections 2.1 and 2.2.

Table 2 Real Pipeline Stock

	Field Alpha	Field Bravo	Total
	kg	Kg	kg
N2	166,786	255,147	421,933
CO2	(-504,728)	4,816,148	4,311,420
C1	5,206,866	14,366,841	19,573,707
C2	3,977,723	2,397,806	6,375,529
C3	2,785,383	(-812,473)	1,972,910
IC4	751,988	202,924	954,912
NC4	1,552,043	102,636	1,654,679
IC5	328,169	412,012	740,181
NC5	410,196	57,509	467,705
C6	(-849,384)	236,605	(-612,779)
C7	(-163,564)	296,035	132,471
C8+	354,973	300,008	654,981
Total	14,016,451	22,631,198	36,647,649

There are some negative values (in brackets) which means, for example, that Field Alpha has been allocated more CO_2 at the gas plant inlet than it has exported. The problem with these figures is illustrated more explicitly when expressed on a mass percentage basis as shown in Table 3, especially when compared against the typical Field export compositions presented in Table 4.

Table 3 Real Pipeline Stock Compositions

	Field Alpha	Field Bravo	Total
	wt%	wt%	Wt%
N2	1.2%	1.1%	**1.2%**
CO2	(-3.6%)	21.3%	**11.8%**
C1	37.1%	63.5%	**53.4%**
C2	28.4%	10.6%	17.4%
C3	19.9%	(-3.6%)	5.4%
IC4	5.4%	0.9%	2.6%
NC4	11.1%	0.5%	**4.5%**
IC5	2.3%	1.8%	2.0%
NC5	2.9%	0.3%	**1.3%**
C6	(-6.1%)	1.0%	(-1.7%)
C7	(-1.2%)	1.3%	0.4%
C8+	2.5%	1.3%	1.8%
Total	100.0%	100.0%	100.0%

* Though the values presented are taken from a real system, the Field names are fictitious in order to anonymise the data.

Table 4 Average Export Compositions

	Field Alpha	Field Bravo
	wt%	wt%
N2	1.8%	0.5%
CO2	9.9%	12.8%
C1	48.7%	61.7%
C2	14.6%	11.6%
C3	14.4%	7.2%
IC4	1.9%	1.1%
NC4	5.0%	2.4%
IC5	1.1%	0.7%
NC5	1.3%	0.8%
C6	0.8%	0.8%
C7	0.2%	0.4%
C8+	0.1%	0.1%
Total	100.0%	100.0%

In the absence of measurement uncertainty it might be expected that the Fields' pipeline stock compositions would be similar to their export compositions - this is clearly not the case. As this is real data, the drifts in pipeline stock compositions may be due to the effect of small systematic biases in the measurements* accumulated over a period of time.

However, the total pipeline stock composition shown in Table 3 seems more reasonable than the individual Field compositions, having only one negative value and appearing more consistent with the combined Fields' export composition. The emboldened figures indicate values that lie between the Field export composition values. If measurement error was the sole cause of the anomalous stock compositions it would be expected that the total stock composition would be as unrepresentative as the Field values.

The only other cause of these anomalous stock compositions is the allocation system methodology itself and in particular the validity of the assumption presented at the end of Section 2.2, i.e. that gains and losses cancel over a period of time.

In the next section the validity of this statement is examined using the simplified model, described in Sections 2.1 and 2.2, to eliminate the effects of measurement uncertainty.

3 ANALYSIS OF ALLOCATION SYSTEM EQUATIONS

3.1 Simplified Pipeline Allocation Model

In order to determine if the allocation equations themselves are contributing to the anomalous stock values a simplified spreadsheet model was constructed. This was required so that the effect of measurement uncertainty could be eliminated. The model is illustrated schematically in Figure 2.

* In using the term measurement bias in this context it should be emphasised that it is not being suggested that there were any faults with the meters or chromatographs. The instruments were of a fiscal standard, calibrated correctly and properly maintained. However, any real instrument is not perfect and will exhibit small biases which will accumulate over a period of time. The allocation system stock changes are small compared with the metered quantities used to calculate them and as the stock change is calculated as the difference between these relatively large flow rate figures, even small biases appear amplified in the pipeline stock values.

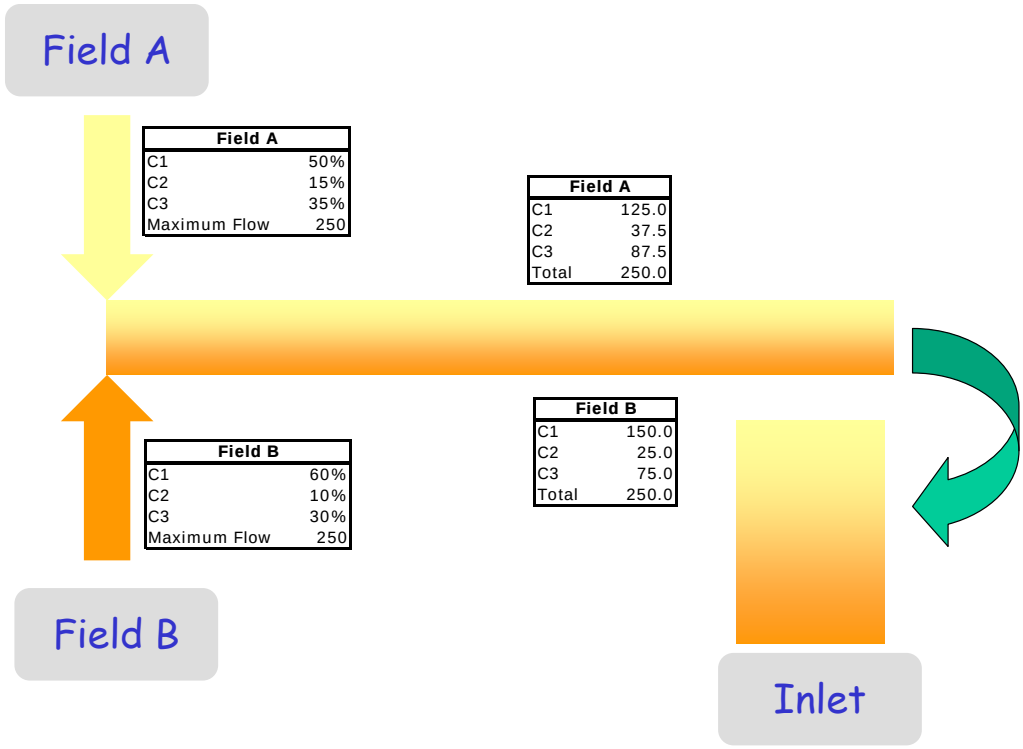


Figure 2 – Schematic of Simplified Pipeline Allocation Model

The model consists of two Fields, A and B, exporting at the same entry point into a pipeline. The gas exported has three components (C1, C2 and C3) and the flow is incompressible so that the total exported offshore is reflected by an equal quantity being displaced from the pipeline and metered at the inlet onshore. The pipeline is such that it has a minimum residence time of one day. The Fields have different compositions but these remain fixed. The flow rates of the two Fields are allowed to vary independently and randomly between zero and a maximum value on a daily basis. The units are arbitrary but may be considered to be mass or molar. The initial pipeline stock attributed to each Field is equal to one day's maximum flow. The compositions, flows and initial stocks are indicated on Figure 2.

Though the total metered inlet exactly sums to the total Field export on a day the compositions will generally be different as the Field flows are varying independently. The model was run using a Monte Carlo approach to vary the Field export flows and run over 100 days. The allocation system described in Section 2.2 was applied in the model and the daily pipeline stocks calculated for each Field at a component level. The results are presented in Figure 3 for Field A and Figure 4 for Field B.

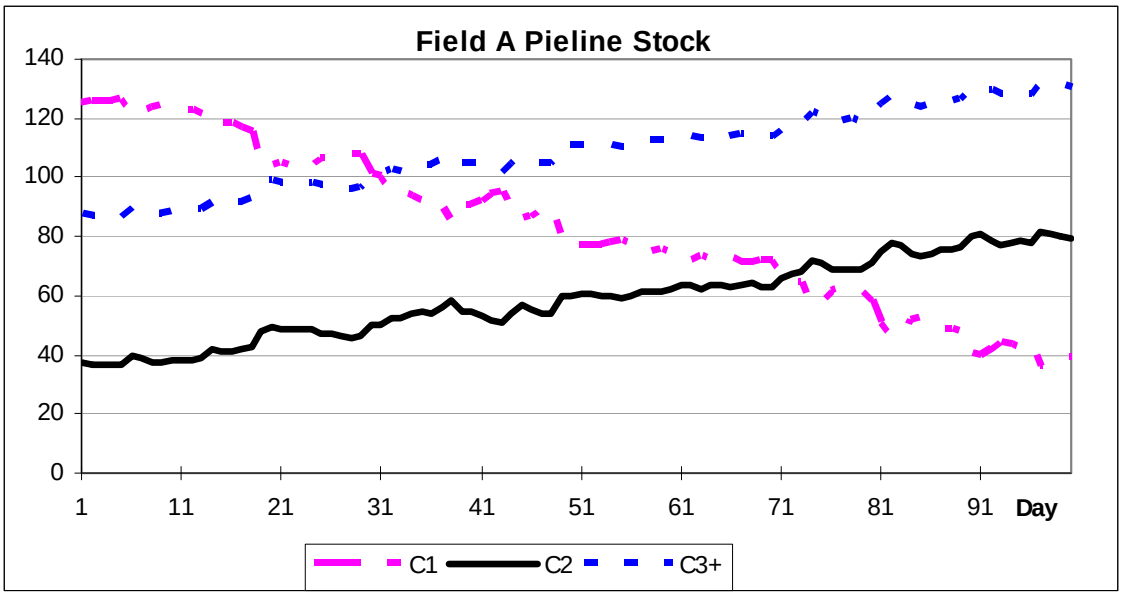


Figure 3 – Field A Pipeline Stock

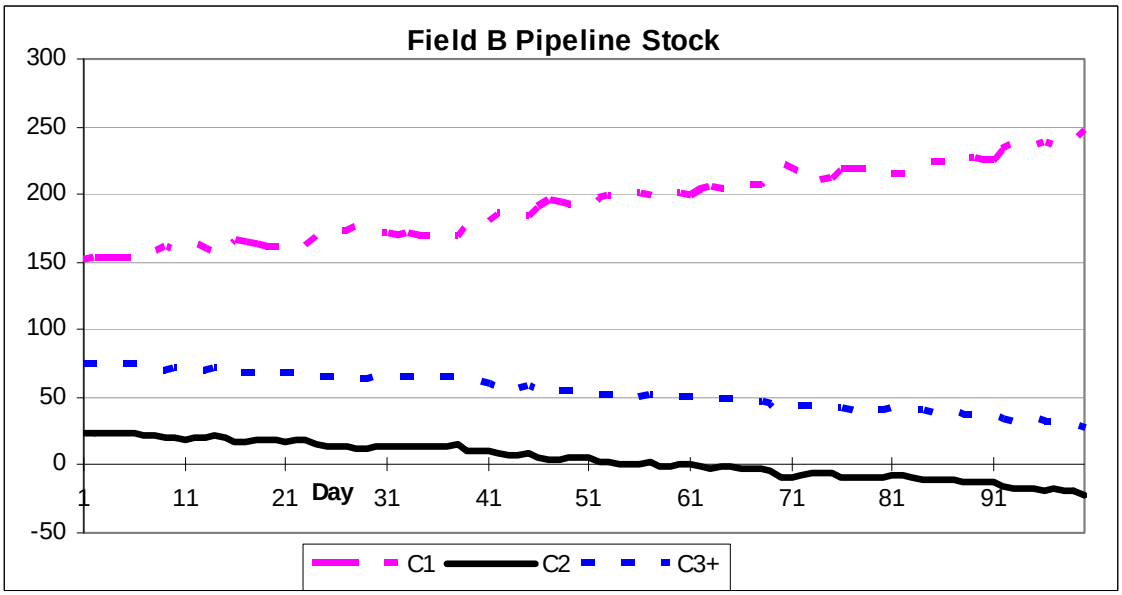


Figure 4 – Field B Pipeline Stock

The charts clearly show that the component stock compositions of the two Fields systematically drift. Field A's C1 stock drops whilst Field B's rises by an equal and opposite quantity. The converse behaviour is observed with C2 and C3. These component stock levels continually diverge, either rising indefinitely are falling indefinitely below zero.

Since in this theoretical model the measured flows and compositions are perfect it would be expected that the total stock composition does not exhibit systematic component drift and this is confirmed in Figure 5.

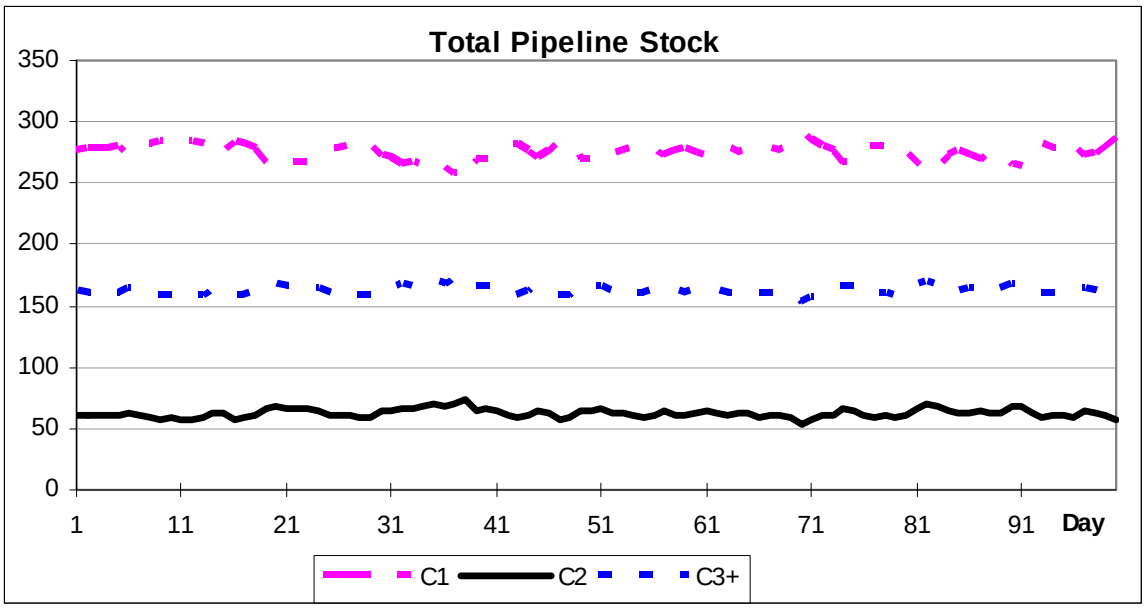


Figure 5 – Total Pipeline Stock

3.2 Conclusions from Allocation Model Results

The following conclusions maybe drawn from these results (and further analysis conducted with the model not presented in the paper):

- At a component level, the expectation that the gains and losses cancel over a period of time is not correct
- The difference between export and allocated inlet diverges with time at a component level
- The more dissimilar the Field compositions the faster the divergence
- The Field richer in a component is systematically under-allocated that component at the inlet – i.e. its pipeline stock of that component increases
- A Field's total pipeline stock remains roughly constant meaning that decreases in components are offset by increases in other components
- The Field level compositional stock drift is solely due to the allocation methodology
- The allocation equations are unstable

The conclusion that a Field richer in a component will experience a systematic increase in pipeline stock of that component and vice versa for the other Field, is observed in the real data presented in Table 3 and Table 4 for nine out of the twelve components. This indicates that the drift in the real stocks is partly due to the allocation system equations and not solely measurement uncertainty effects.

At this point it may be observed that though these results are interesting the fact that the under allocation of components that a Field experiences are offset by gains in other components, it may be asserted that the overall material impact of this is unimportant. However, the component that a Field is compensated with may be less valuable than the one it has been under allocated, e.g. compensation with CO_2 or N_2 at the onshore inlet for hydrocarbons is a loss of value. Similarly relatively valuable NGL components compensated for by gas components (under current market conditions) represents a loss also.

The model indicates that in a real system Fields rich in NGLs will tend to be systematically under-allocated these components at the inlet. Similarly Fields rich in CO_2 will be under-allocated this inert at the inlet at the expense of the other Field. It appears there will be winners and losers as a consequence of the allocation equations used, the system is not equitable.

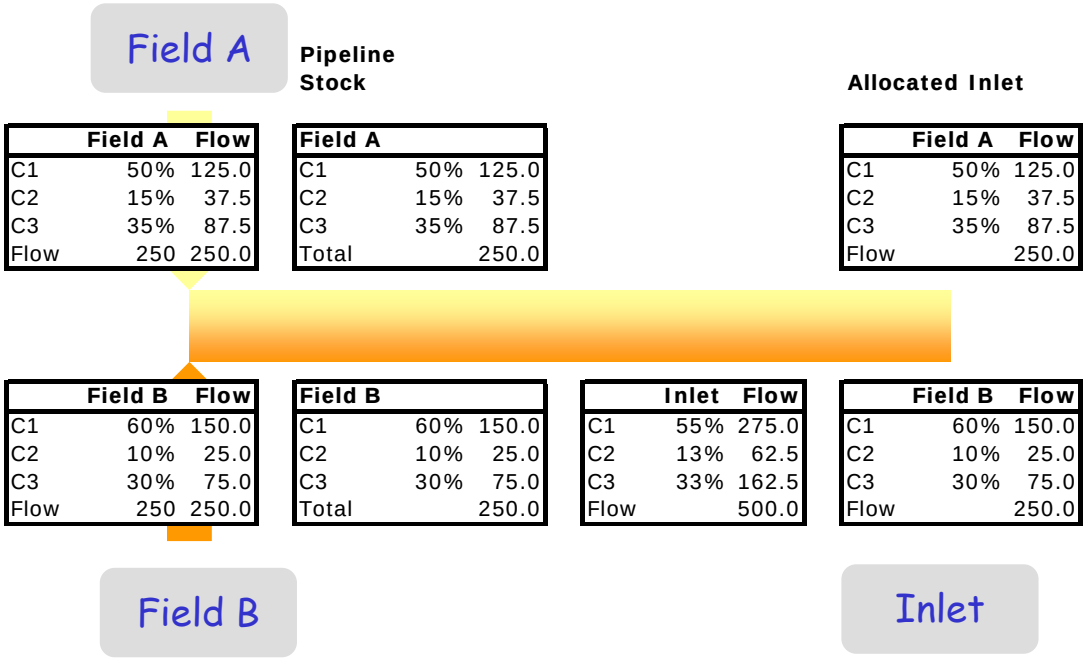
In fact this is clearly illustrated in the real data presented in Table 2. Field Alpha has lower CO_2 export content than Bravo; it also has a negative CO_2 stock meaning it has been allocated more CO_2 at the inlet than it has exported. Also, Field Alpha is richer in the NGL components and experiences an increase in stock of virtually all these heavier components meaning it has been under allocated these components at the inlet. Hence, the data suggests that Alpha has been significantly disadvantaged in that it has been systematically allocated more CO_2 and less NGLs at the plant inlet than it exported.

Some allocation systems may not allocate pipeline stock operating on the assumption that "you get out what you put in" over a period of time and hence allocation of stocks is not required. Whether they are explicitly calculated or not they do represent a record of the difference between what has been put into and taken out of the pipeline by a Field. Just because pipeline stocks are not calculated doesn't mean that there isn't a problem with the allocation system.

The expectation that the gains and losses in pipeline stock would tend to cancel over a period is palpably untrue. The next section examines in detail why this is the case.

3.3 Analysis of Stock Drift

Using the simplified model described in Section 3.1, and varying the Field export flow rates in a systematic fashion (rather than randomly), the details of the allocation calculations can be analysed. Consider the case where initially both Fields are producing at maximum flow under steady state conditions. This is presented schematically in Figure 6:



	Field A	Flow
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Flow	250	250.0

Field A		
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Total		250.0

	Field A	Flow
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Flow		250.0

	Field B	Flow
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Flow	250	250.0

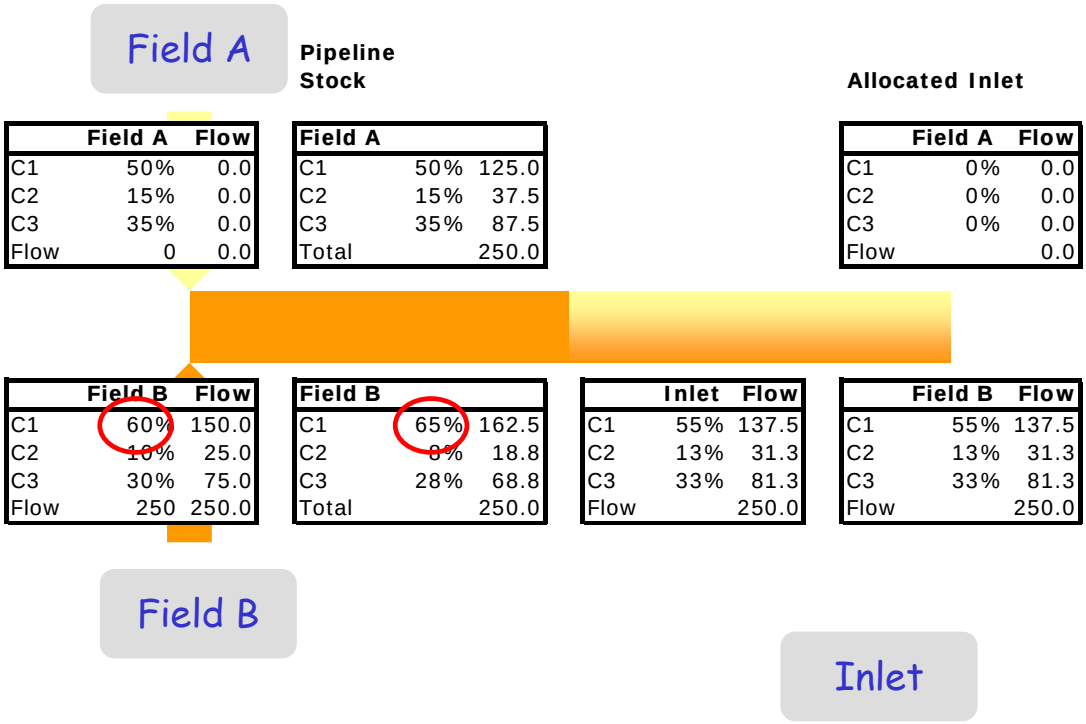
Field B		
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Total		250.0

	Inlet	Flow
C1	55%	275.0
C2	13%	62.5
C3	33%	162.5
Flow		500.0

	Field B	Flow
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Flow		250.0

Figure 6 – Day 1 Steady State

As can be seen under such conditions the metered inlet exactly equals the sum of the exports at a component level. Under these circumstances both Fields' allocated inlet is exactly what they exported and their stock remains unchanged. On Day 2 Field A shuts down whilst Field B's production remains steady:



	Field A	Flow
C1	50%	0.0
C2	15%	0.0
C3	35%	0.0
Flow	0	0.0

Field A		
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Total		250.0

	Field A	Flow
C1	0%	0.0
C2	0%	0.0
C3	0%	0.0
Flow		0.0

	Field B	Flow
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Flow	250	250.0

Field B		
C1	65%	162.5
C2	8%	18.8
C3	28%	68.8
Total		250.0

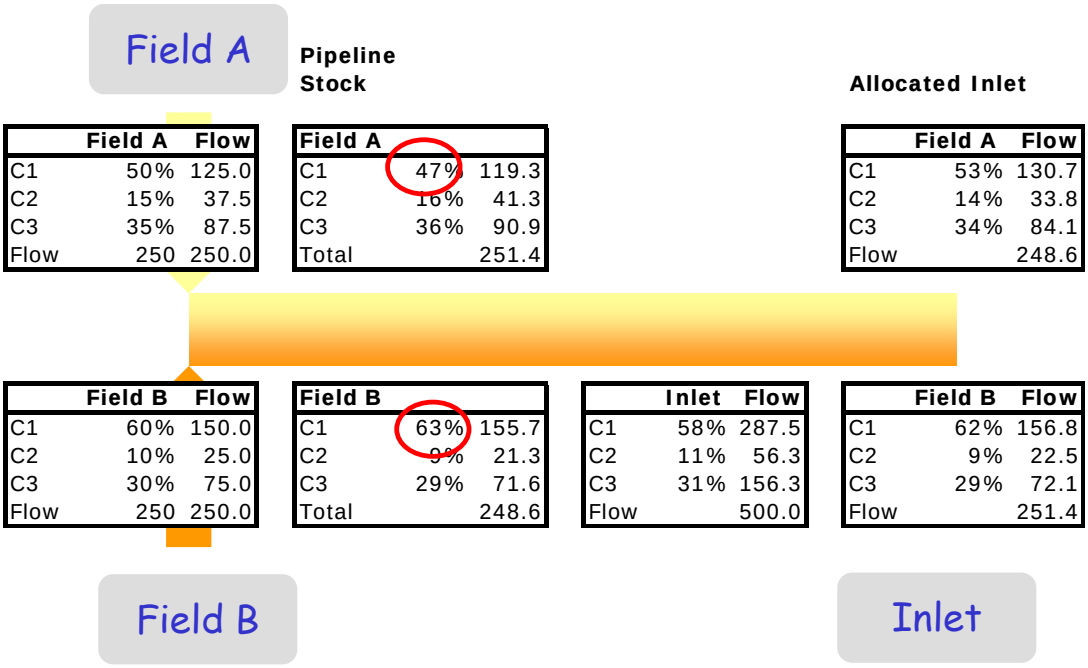
	Inlet	Flow
C1	55%	137.5
C2	13%	31.3
C3	33%	81.3
Flow		250.0

	Field B	Flow
C1	55%	137.5
C2	13%	31.3
C3	33%	81.3
Flow		250.0

Figure 7 – Day 2 Field A Shuts Down

With only one Field flowing exactly half the pipe contents are displaced through the inlet which comprises a 50:50 mixture of Fields A and B, all of which is allocated to Field B on Day 2. Analysing C1 specifically: since Field B is richer in this component than Field A it is allocated 12.5 units less at the inlet than it exported and its stock increases by this amount. Conversely, it experiences a drop in C2 and C3 stock. It can also be seen that Field B's C1 stock expressed as a percentage is now higher than its export figure (highlighted by ellipses) – it has started to diverge.

Field A's stock is constant since it wasn't flowing; however the next Day Field A starts up again:



	Field A	Flow
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Flow	250	250.0

Field A		
C1	47%	119.3
C2	16%	41.3
C3	36%	90.9
Total		251.4

	Field A	Flow
C1	53%	130.7
C2	14%	33.8
C3	34%	84.1
Flow		248.6

	Field B	Flow
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Flow	250	250.0

Field B		
C1	63%	155.7
C2	9%	21.3
C3	29%	71.6
Total		248.6

	Inlet	Flow
C1	58%	287.5
C2	11%	56.3
C3	31%	156.3
Flow		500.0

	Field B	Flow
C1	62%	156.8
C2	9%	22.5
C3	29%	72.1
Flow		251.4

Figure 8 – Day 3 Field A Starts Up Again

Now with both Fields flowing the entire pipeline contents are displaced through the inlet and this now comprises a 25:75 mixture of Fields A and B respectively. Being rich in Field B gas, the C1 metered at the inlet is greater than the combined C1 export and both Fields are allocated more C1 at the inlet than they exported and hence their C1 pipeline stocks drop. In order for Field B's C1 stock to return to its initial Day 1 level it needed to be allocated 12.5 more units at the inlet than it exported but it is only allocated 6.8 units more – hence its C1 stock drops but not back to the initial level.

Though Field B has partially returned its C1 stock towards its initial value, Field A's C1 stock has now dropped below its initial level and expressed as a percentage is now lower than its export figure (highlighted by ellipses) – it too has started to diverge in the opposite direction to Field B. In fact the more Field B returns its C1 back to it is initial level the more Field A's C1 stock is caused to drop. It appears that any deviation in one Field's stock can not be corrected without causing the other Fields stock to diverge in the opposite direction.

If the system remained in steady state the stocks would remain unchanged. However, to continue the analysis Field B now shuts down:

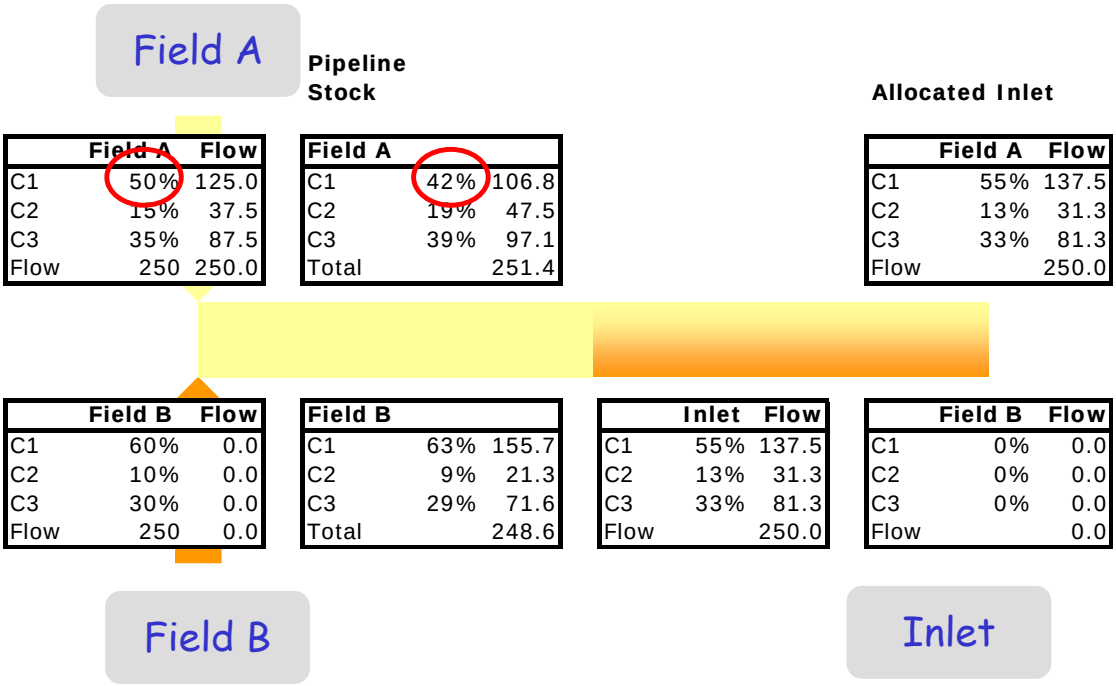


Figure 9 – Day 4 Field B Shuts Down

Again with only one Field flowing exactly half the pipe contents are displaced through the inlet and this is a 50:50 mixture of Fields A and B, all of which is allocated to Field A. Now Field A is allocated 12.5 units more of C1 at the inlet than it exported and its stock consequently decreases by this amount causing it to diverge further. Now Field B restarts:

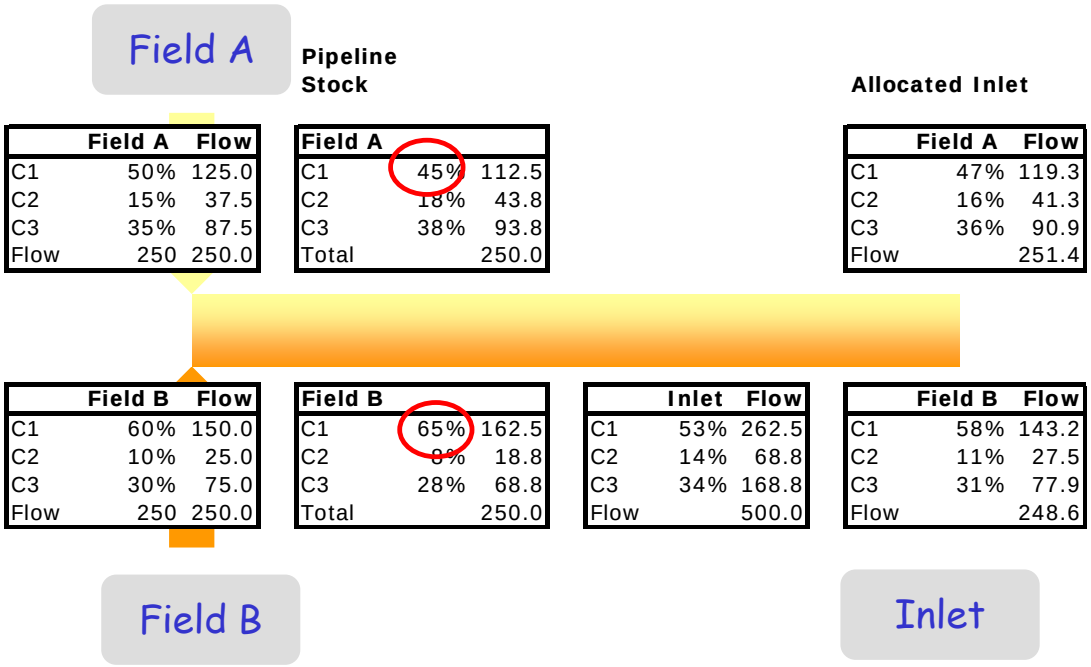


Figure 10 – Day 5 Field B Starts Up Again

The inlet is 75:25 mixture of Fields A and B respectively. The inlet being Rich in Field A results in both Fields being allocated less C1 at the inlet than they exported and hence their C1 pipeline stocks increase. Field A's C1 stock is corrected to some extent but at the expense of Field B's C1 stock diverging again.

After 5 days, Field A's C1 stock is lower than its export content and Field B's is higher than its content, they are diverging in opposite directions. As observed in the Monte Carlo simulations the Field richer in a component experiences a systematic increase in its stock of that component and the Field leaner in that component experiences an equal and opposite decrease.

Having observed the effect and analysed why it occurs the next section presents modified equations to eliminate the instability in the equations.

4 ALTERNATIVE ALLOCATION METHODOLOGY

4.1 Stock Composition Based Allocation Model

Instead of using a Field's gas export composition to allocate the inlet, the modified approach is to use its stock composition. Equation (1) is amended to:

$$AI_{A,c} = \mathrm{M}I \times xI_{\mathrm{c}} \left[\frac{\mathrm{M}E_{\mathrm{A}} \times \left(xSO_{\mathrm{A,c}} \right)}{\mathrm{M}E_{\mathrm{A}} \times \left(xSO_{\mathrm{A,c}} \right) + \mathrm{M}E_{\mathrm{B}} \times \left(xSO_{\mathrm{B,c}} \right)} \right] \tag{4}$$

Where,

$$xSO_{A,c} = \frac{SO_{\mathrm{A,c}}}{\sum_{c} SO_{\mathrm{A,c}}} \tag{5}$$

Equations (2) and (3) are unchanged.

This minor change in the mathematical approach generates similar allocation results to the export composition based approach. However, though similar there are small differences in the daily allocated quantities. Because the stock compositions more closely reflect the measured inlet composition, and there is a feedback mechanism in that the Fields' stocks are influencing the allocated quantities at the inlet, the stocks remain stable. This is illustrated using the simplified model but with the allocation amended in accordance with equation (4) - the results are presented in Figure 11 and Figure 12.

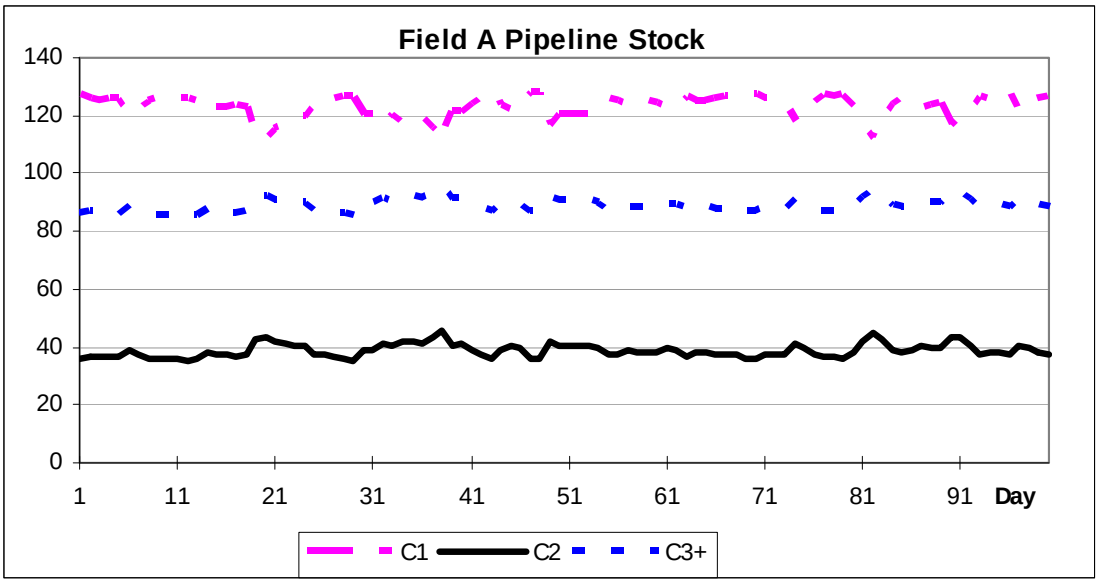


Figure 11 – Field A Pipeline Stock – Stock Based Allocation

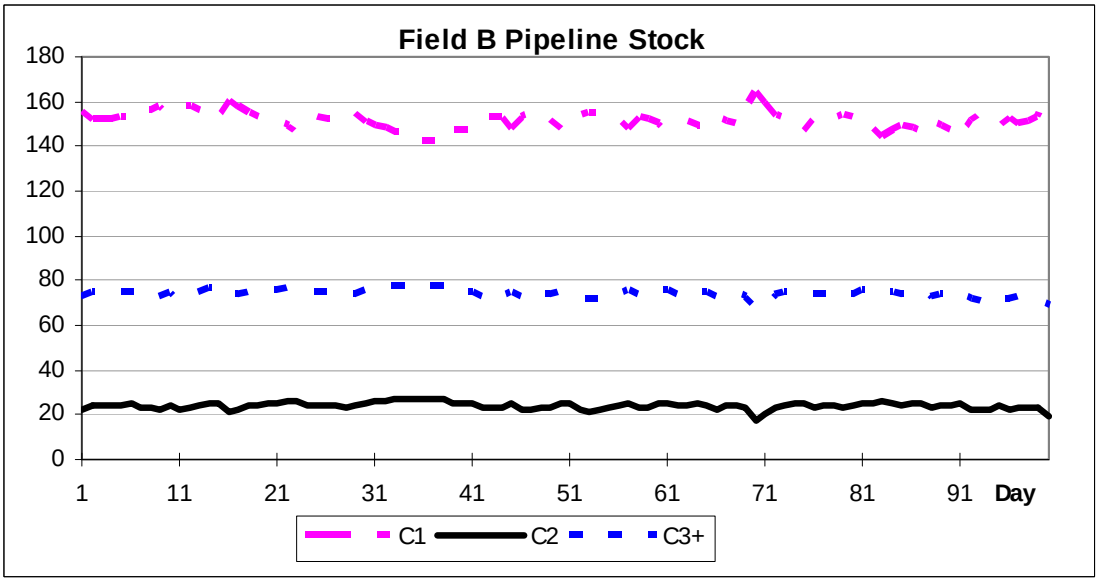
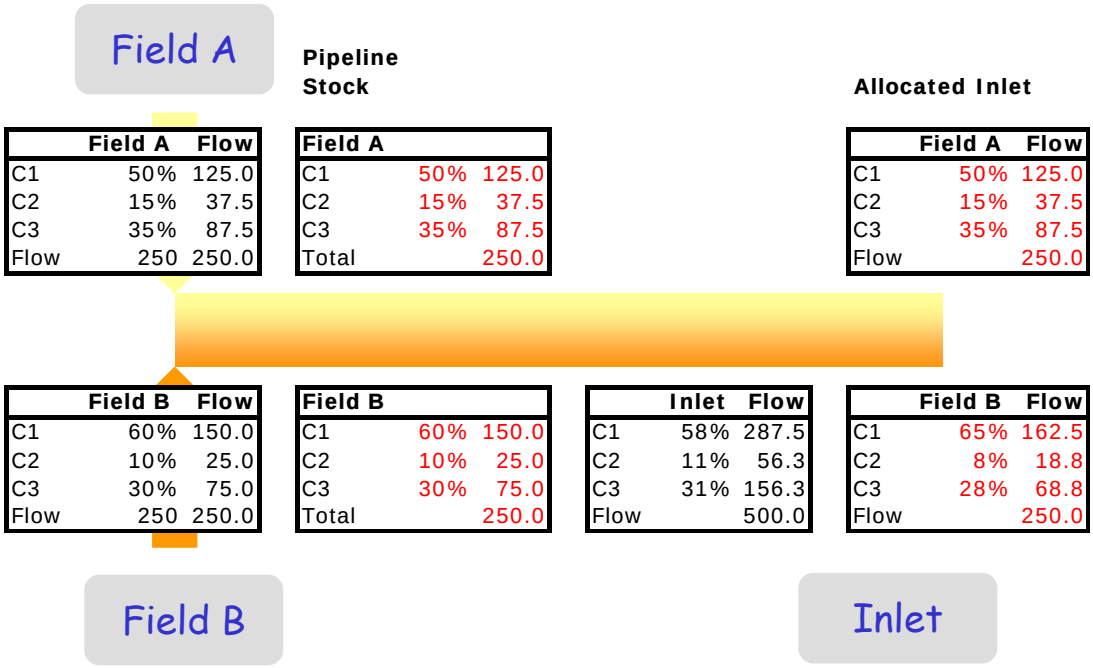


Figure 12 – Field B Pipeline Stock – Stock Based Allocation

Returning to Day 3 of the example presented in Section 3.3 and modifying the allocation calculations in accordance with equation (4):



	Field A	Flow
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Flow	250	250.0

Field A		
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Total		250.0

	Field A	Flow
C1	50%	125.0
C2	15%	37.5
C3	35%	87.5
Flow		250.0

	Field B	Flow
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Flow	250	250.0

Field B		
C1	60%	150.0
C2	10%	25.0
C3	30%	75.0
Total		250.0

	Inlet	Flow
C1	58%	287.5
C2	11%	56.3
C3	31%	156.3
Flow		500.0

	Field B	Flow
C1	65%	162.5
C2	8%	18.8
C3	28%	68.8
Flow		250.0

Figure 13 – Day 3 Field A Starts Up Again – Stock Based Allocation

Now the closing stock compositions are exactly equal to the Field export compositions. Field B's opening stock C1 content was 65% which is higher then its export composition but this means that in the stock based allocation Field B is allocated a greater proportion of the inlet than in the export based allocation and accordingly results in a greater reduction in its pipeline stock.

Since the stock content of a component itself is involved in the calculation there is a feed back mechanism so that the allocation equations now tend to rectify the stock composition back towards the export composition. For example, if the stock content of a component rises, on the next day it automatically influences the allocation such that the Field is allocated more of that component and hence tends to reduce its stock level of that component.

There is one word of caution with this approach however. Should any of a Field's component stock levels become negative the allocation results from then on become wildly unstable. This problem is easily avoided however by allocating zero of that component in the inlet to that Field and any export of that component is added to its stock.

4.2 Application to Real Data

Finally could the modified allocation approach have helped in the real system described in Section 2.3?

Figure 14 shows the pipeline stock propane content allocated to the two Fields over a period of approximately 3 months using the existing export composition based approach. As can be seen Field A's stock is higher than its export C3 content and Field B has a negative C3 content; neither stock level reflects the actual export C3 content of the Fields.

Using the same measurement data for the period, the allocation was adjusted to be stock composition based and the results are presented in Figure 15. As can be seen the stock compositions are in good agreement with the actual export compositions throughout the period.

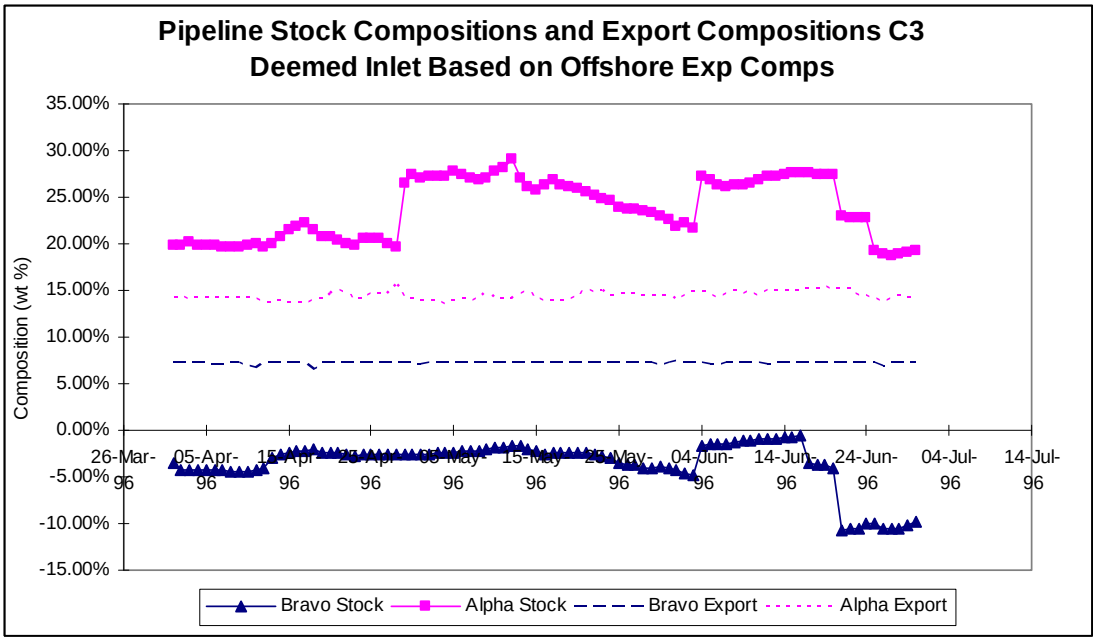


Figure 14 – Real System – Allocated Pipeline Stock for Propane (C3)

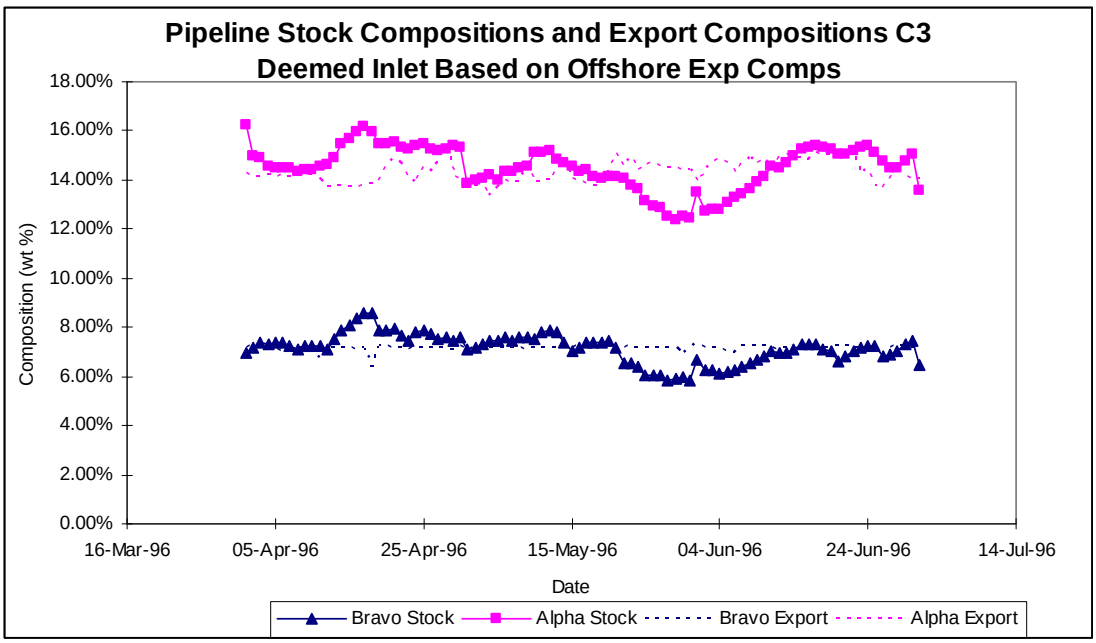


Figure 15 – Real System – Stock Composition Based Allocated Pipeline Stock for Propane (C3)

5 CONCLUSIONS

Allocation equations associated with pipeline systems will generally be non-linear and include a dynamic element. Such equations are well recognised to be susceptible to unstable behaviour [1].

The real system described in Section 2 had been operating for a number of years before the problem with the allocation methodology was detected. The reason for this is that the effect is subtle and obscured by measurement uncertainties. In addition, the expectation that "you get out what you put in" over a period of time appears intuitive and at first sight reasonable but can be demonstrated to be untrue.

There exists a preference for simple transparent allocation systems. However, as has been demonstrated in this paper, simple systems can produce unexpected and inequitable results. Though the paper has been centred on pipeline allocation the issues have wider implications for allocation systems in general and in particular the methods used to establish their robustness, stability and equitability.

The following points may be concluded from the analysis carried out in this paper:

- Even simple equations can produce unexpected results and lead to bias in allocation
- The requirement to test rigorously allocation system assumptions, equations, methods and logic is necessary at the design stage
- The use of simplified models such as those presented in Section 3.1 are powerful tools in testing understanding the robustness and equitability of allocation systems
- Allocation systems can be designed that are stable, robust and equitable.

NOTATION

AI	Allocated Inlet
ME	Metered Export
MI	Metered Inlet
xE	Mass fraction of a component measured at Export
xI	Mass fraction of component c measured at Inlet
xSO	Mass fraction of component c in allocated Pipeline Stock
CS	Closing Pipeline Stock
OS	Opening Pipeline Stock
ΔS	Change in pipeline stock

Subscripts

A	Field A
B	Field B
c	component

6 REFERENCES

[1] Non-Linear Dynamics and Chaos, Steven H.Strogatz, published 2000, ISBN 0-7382-0453-6.