Improving Analysis of Hazard & Risk Identification Workshops

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Risk identification is a key step at the start of all programmes of risk management. Facilitated hazard and risk identification workshops such as PHA, HAZID, FMEA and HAZOP are important tools used across industry for the identification and characterisation of risks. In times of cost-saving and cut-backs, risk identification is an area where improvement may be sought. Any such changes must be intelligently driven by data-led process improvement and optimisation rather than just cost-savings, or risk negatively impacting the entire safety management regime.

A study has been undertaken to investigate the potential for improvement to such techniques that could be achieved by implementing a novel process variant to extract and anonymise additional more granular data from these studies. Such data, once extracted from studies, yields opportunities to improve understanding of the way the study has occurred.

For example, it is commonly understood that facilitated workshops like HAZID and HAZOP usually speed up. (This assertion has been verified by a survey conducted of BCECA's DS&E committee (British Chemical Engineering Contractor's Association, Design Safety & Environmental)). This implies that there is a changing rate of progress through the scope of study. Should the rate of progress achieved by the end of the study be targeted as a constant rate throughout? How fast is too fast? By how much do studies accelerate? What factors affect this rate of change?

Anonymising data means that there is potential for cross-industry sharing and the development of a large data set, from which new statistically-backed studies, developments and improvements to the processes could be made. Further potential benefits can be considered including application to study duration/cost estimation and facilitator / participant training methods.

A detailed methodology and case studies are presented demonstrating the outcomes of developmental trials of this approach. These detail the potential of this technique to open new fields of research into the way that studies are conducted and to inform process improvement.

Keywords: HAZOP, HAZID, Risk Assessments, Big Data, Process Improvement

Introduction

Industry Context

The petrochemical industry is in a time of great challenge. Low oil prices drove owners and operators into a cycle of efficiency savings and cost reductions to meet depressed market conditions. Since the downturn in late 2014 the oil price has been roughly half of that seen for much of the preceding decade. This change in oil price instigated a drive to reduce production costs and is a constant, 'fact of life' for engineers in roles all over the oil and gas industry.

This new environment brings with it a number of challenges, one of the most critical of which is maintaining focus and priority on safety. Efforts to reduce costs in operations and in design processes place potential time pressures and cost restrictions on safety-related design elements with the potential for a failure of engineering process to lead to significant health, safety and environmental consequence to end users.

"The 100 Largest Losses 1974-2015" is an annual report published by the insurer, Marsh & Mclennan, regarding large property damage loses in the hydrocarbon industry. The 2016 issue of this report [Carpenter, 2016] makes a correlation between dips in the oil price and the occurrence a few years later of increased numbers of major process safety incidents. This, they speculate, is attributed to cost-saving efforts resulting in cut-backs to aspects of safety engineering within design phases, with the time lag coming from the delay between projects being in design and the later experience of increased incidents once those projects are in operation.

Similarly, last year's DNV GL Industry Outlook raises the same issue, backed by survey statistics [DNV GL, 2017]. This survey, "asked respondents whether cost-cutting initiatives in their organization are increasing health and safety risk. Only one in five (19%) said yes, but there is reason to believe that this underestimates the issue." The report goes on to indicate that this may be a significant underestimation, again due to the interval of time between spending cuts occurring in the design phases of projects and the resultant designs seeing increased incident occurrence during operation. It may be three to five years before designs currently undergoing concept and Front End Engineering Design (FEED) in today's atmosphere of cost saving are operating in the field so a significant lag in safety statistics is to be expected.

It is clear from these sources that it is critical for safety professionals in engineering design to understand that the cost savings currently being demanded of them must not be met by, 'cutting safety'. The only alternative available is to do more with less, to improve the efficiency and quality of product and processes to allow improved results, in the same or less time, for the same or less money. This challenge has been a key driver in the development of this research.

Introducing Facilitated Safety & Hazard Reviews (FSHR)

There are a wide range of tools available to industry for the identification of risks and hazards as required by risk management processes. 'Facilitated Safety Hazard / Risk' review (FSHR) is a catch-all term of convenience which is used here to simplify reference to the group of design study techniques which are being considered here.

FSHR is a family of closely comparable hazard identification study types. Membership of this grouping is dependent on the presence of four identifying features in their methodology.

1. FSHR studies are run as facilitated discussion and brainstorming workshops with a small, normally multidisciplinary, team of engineers and other specialists.

2. FSHR studies are concerned with the identification of hazards or risks and the associated safeguards and mitigations. They also identify recommendations or actions in consideration of the improvement of control of identified risks.

3. FSHR studies are iterative in their structure in that they repeatedly apply looping processes of assessment to different aspects of a scope. In some cases, these iterative loops are nested.

4. FSHR studies are recorded, often by a dedicated scribe, in a formal, structured "line item" style using some form of worksheet, usually on a computer.

There is a bewildering array of hazard identification techniques in use currently. Gould et al [Gould, 2000] identify thirty-eight differently named techniques for risk identification, from which about 30% fulfil the criteria above. Broadly, these can be divided into three groups: HAZOP style (including HAZOP, CHAZOP, SAFOP and EHAZOP), HAZID style (including HAZID, ENVID, What-IF, CHA and PHA) and FMEA style (Including FMEA and FMECA).

These groups cover many of the currently most popular methods and techniques, and account for a large part of the studies being conducted in design phases to identify and characterise risks and hazards.

Improving FSHR Practice

Accepting that there is a goal to improve performance in this field, to support better outcomes for the safety of developed designs, it is then the challenge to develop a method to achieve this improvement. FSHR studies are well-established industry techniques with a strong body of knowledge regarding the way that they can be carried out. However, the development of a novel variation to these existing methodologies has been conceived by applying quantification / metrification, which may allow process improvement techniques to be applied in a way which was not possible previously.

FSHR studies can fail in such a way as to result in a more dangerous design, and potential eventual health, safety & environmental consequences, whenever there is a failure to identify or to take forward a hazard for consideration. By failing to carry this hazard beyond identification stage, none of the safeguards, mitigations or hazard management processes can address it. This gives it the potential to be a "Black Swan" event or an "unknown unknown".

This leads to the central means by which FSHR should be sought to be improved: any reduction in the number of process failures will lead to improvement in the proportion of the total hazards which successfully make it through the study to the end of the risk management process and will result in an improved, safer design. This also extends to improving quality of outputs, and by extension to improving speed of study if such improvement coincidentally leads to more efficient studies – speed should not be pursued as a goal in and of itself if doing so compromises quality.

A well-tested strategy for the development from first principles of process improvement initiatives is that of DMAIC (Define, Measure, Analyse, Improve, Control) as popularised by practitioners of Six Sigma Methodologies. The principles of DMAIC and Six Sigma centre around applying quantification to a process, measuring results and analysing them, then seeking to develop improvements to reduce variability in the process. Once the process is operating at an improved, understood level with low variability, it can be experimentally tailored to change parameters, using the measurement tools to observe results of that change, allowing the selection of beneficial changes and the discarding of negative ones.

To achieve any form of such process improvement, quantification, and rigorous, reviewable data analysis is seen as an essential first step, both in managing the change and also in proving improvement to a suitable academic standard. FSHR faces immediate issues here in that the data currently collected during studies appear to be of a very poor suitability to quantification and data aggregation. The records from FSHR meetings are essentially meeting minutes, though with some elements of structure, already a distillation of the actual meeting process and are made up largely of prose text. Further there are additional barriers to the sharing of data between companies for any academic research purposes: given the sensitive nature of the information thus recorded they are often highly confidential.

To provide more information of a suitable type to inform later process improvement, two key ideas are proposed:

• That quantification through granular (line item level) time measurement of studies be added to existing records, allowing the development of rate-based metrics of progress and information about study acceleration or deceleration behaviour.

• That a method be implemented for the abstraction of information regarding the nature of a line item within a study, to allow the anonymisation of data sets and removing issues of corporate sensitivity.

Literature Review

A literature review was completed to gain general information about FSHR current practice and to attempt to establish if any prior research had been completed on the possibility of granular quantification and anonymisation of FSHR studies. A number of studies and papers deal in part with quantified data associated with FSHR, particularly from the perspective of estimation and process improvement, but none were found to have considered the application of quantification within a study at a line item level.

Of particular interest were papers found which detailed potential percentage improvement in study durations, detailing some tabulated durations [Bridges, 2009], and which made statements regarding percentage compliance of studies with best practice [Tew, 2017]. Another paper [Dunjo, 2011] approached the issue from the perspective of study duration estimation. This paper provides data on the node timings of five case studies completed which demonstrates an average of approximately three hours per node, with an exception noted that the first node takes double the average. This is the only found example of timed data being taken at any level more granular than the study as a whole.

Survey

Seeking more information on current industry practice, a survey was completed of oil & gas contracting company senior technical safety professionals, through the auspices of the British Chemical Engineering Contractor's Association (BCECA) Design Safety & Environmental Committee. This survey gathered information about current practices in terms of process, procedures, study timings, team composition, study records and other aspects.

The survey successfully established a number of consensus statements which could be taken forward for further analysis, with a view to comparison against future case study quantified data. At the same time, a number of survey questions failed to establish a consensus, and in so doing highlighted the sometimes nebulous nature of such "Tribal Knowledge", in contrast to the intended goal of quantified data analysis.

The findings of the survey were analysed and a number of hypotheses formed for comparison against case study data. These statements would be used as a way of demonstrating how quantification could lead to the advancement of understanding of FSHR processes. Six hypotheses were assembled:

1. The rate of progress measured as line items per hour is expected to increase as a study progresses.

2. The rate of value generation may demonstrate a trend differing from the base rate of progress.

3. The average duration of study day should be six hours and ten minutes.

4. The rate of progress or rate of value generation may be affected by study days running longer than six hours and ten minutes.

5. HAZOP should cover 4.2 process P&IDs per day.

6. FSHR studies will proceed with higher rate of progress through less complex drawings.

Proposed Methodology

Over the course of a number of studies, a methodology has been developed and test implemented for the application of line item time stamps in both word processing and spreadsheet based recording packages, to allow the collection of data suitable for experimental comparison against the hypotheses developed in the previous section. Case studies presented in subsequent sections will show the various stages of development of this process. The following is a procedural description of the necessary "bolt on additions" to a FSHR process to implement this process.

If a study is to be conducted with time stamping, this must be established during the development of the meeting / Terms of Reference. The scribe must be conversant with the technique to be used, and additional care must be taken at all stages of recording the workshop. Sufficient time must be given for the additional tasks involved in both preparation and execution.

Each FSHR study worksheet shall be provided with an additional column, normally at the left of the worksheet. This column will be used to record a start time for each line item. Duration of time spent on a line item can then be established by subtracting start time from the start time of the subsequent line item.

As the worksheets are developed, the scribe shall populate this column accurately. For all non-line item elements of the study, including breaks, non-line item discussions (such as those which often occur at the start of nodes and at the beginning and end of days), must be recorded in-line with the study items – i.e. as a blank line marked "BREAK" or similar, with an associated start time such that the entire time of the study can be accounted for. This is to prevent breaks and other non-productive time from distorting the apparent rate of progress.

Once the study has been completed, the FSHR study and associated time stamp data must be processed to develop a complete timeline of the study which can be used for data analysis. These data must be anonymised and stripped of potentially sensitive client information while retaining the following:

*   Drawing information (number of drawings, type of drawings including whether they are process or utility)

*   Alignment of drawings to nodes where relevant

*   At a line item level:

    o   Start times (and hence durations)

    o   Node / guideword / parameter (as applicable)

    o   Level of value represented by line item (see overleaf)

    o   Line item level timing must also be provided for all non-line item time durations e.g. breaks, lunch etc.

The most critical part of post-processing work is the development of value assessment for each line item. This should be completed by the chair, scribe or another individual familiar with the outcomes of the study. The intent of this exercise is to remove any sensitive information from the data set, while retaining information about the level of value generated by an individual line item. A numerical value is assigned to each line item according to the guidance given in the table below. Note that the values proposed here are an initial proposed valuation, and further research is required to confirm appropriate values. The intent is to appropriately characterize the value generated by a line item as a single number.

Table 1 – FSHR line item value

Code	Line item description	Value assigned / multiplier to be applied
A	Novel, fully developed hazard	1
B	Partially original content, with some copying or duplication	0.5
C	Cross-reference to existing item	0.1
D	Statement of negative outcome (i.e. no hazard identified)	0.1
-	Line item resulting in recommendation	Multiply by (1+(Number of actions raised x 1.5)
E	Pre-node description and discussion	0
F	Non-line item duration e.g. break, lunch etc.	0

Once established this data set can be used for further analysis of the resultant time-based data. The key process of efficiently developing accurate time stamps during the FSHR study can be greatly simplified through the use of semi-automated recording tools. It is possible to complete this within Microsoft Word and Excel using macros. An example data set is shown in Table 2 below.

Table 2 – Example data set

ID	Time Stamp	Duration	Descriptor	Recomm.	Value Rating	Rate of Progress	Rate of Value Generation	Guideword	Parameter	Notes
1.00	09:06:56	00:09:25	E	0	0	0.000	0.000	-	-	Start Day 1/ Node 1 Introduction
1.01	09:16:21	00:08:36	A	0	1	6.977	6.977	No	Flow	
1.02	09:24:57	00:10:36	A	2	4	5.660	22.642	No	Flow	
1.03	09:35:33	00:08:46	A	0	1	6.844	6.844	No	Flow	
1.04	09:44:19	00:03:50	A	0	1	15.652	15.652	No	Flow	
1.05	09:48:09	00:12:15	A	1	2.5	4.898	12.245	No	Flow	
1.06	10:00:24	00:11:16	F	0	0	0.000	0.000	-	-	Break
1.07	10:11:40	00:08:12	A	0	1	7.317	7.317	No	Flow	
1.08	10:19:52	00:05:01	F	0	0	0.000	0.000	-	-	Late arrivals join meeting
1.09	10:24:53	00:04:29	A	0	1	13.383	13.383	Less	Flow	
1.10	10:29:22	00:05:09	A	0	1	11.650	11.650	Less	Flow	

Case Study 1

This study was an eight-day long HAZOP which was immediately followed by a day and a half of LOPA (Layers of Protection Analysis) study. The study reviewed elements of a Floating Production, Storage and Offloading (FPSO) field development project. The scope consisted of P&IDs for one of a number of connected satellite wellhead and processing platform facilities being developed for tie-in to the existing FPSO architecture.

The study was completed in the US, with attendance made up of British, US, Norwegian, and Brazilian individuals. Attendance consisted of 12 full time attendees (including facilitator and a dedicated scribe), supported by a further 15 part-time attendees. The HAZOP took up the majority of the total study duration, with LOPA being completed in the final day and a half.

The study reviewed 71 P&IDs. It was not noted how many were process P&IDs and how many utilities. The study scope was split into 24 nodes. 46 recommendations were raised. The study was recorded in PHAPro.

Only basic timing details were available, showing the start and stop of each day and lunch breaks. The following charts of these data were developed for review.
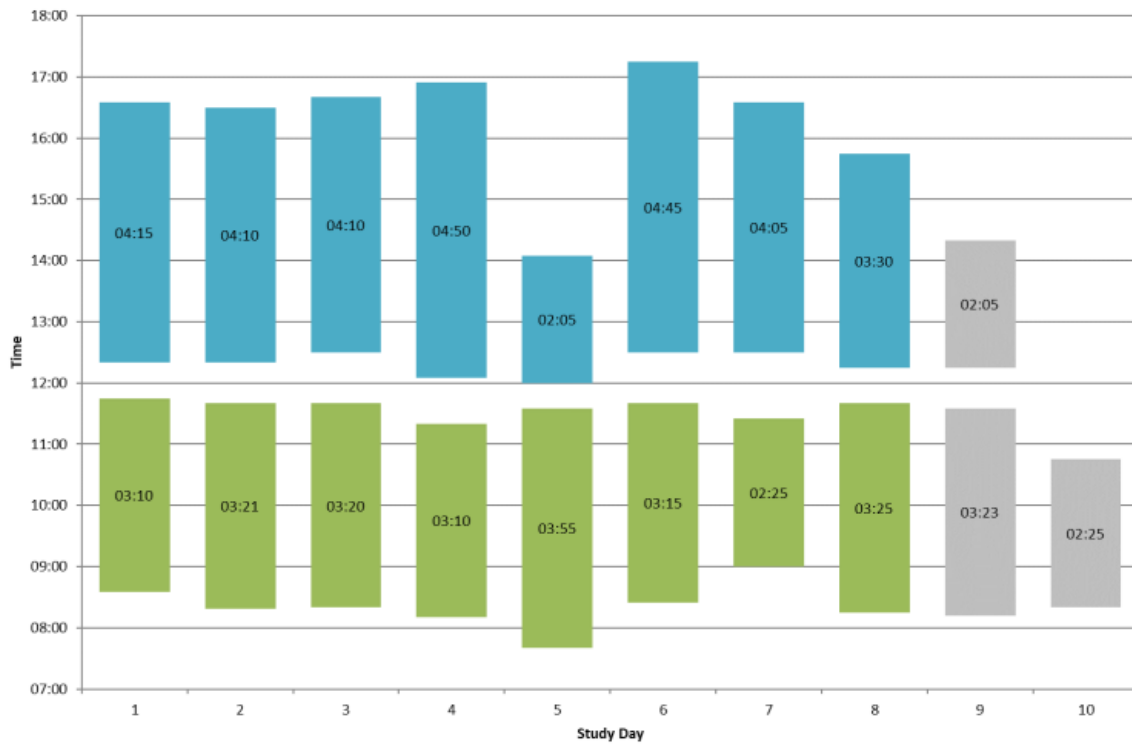
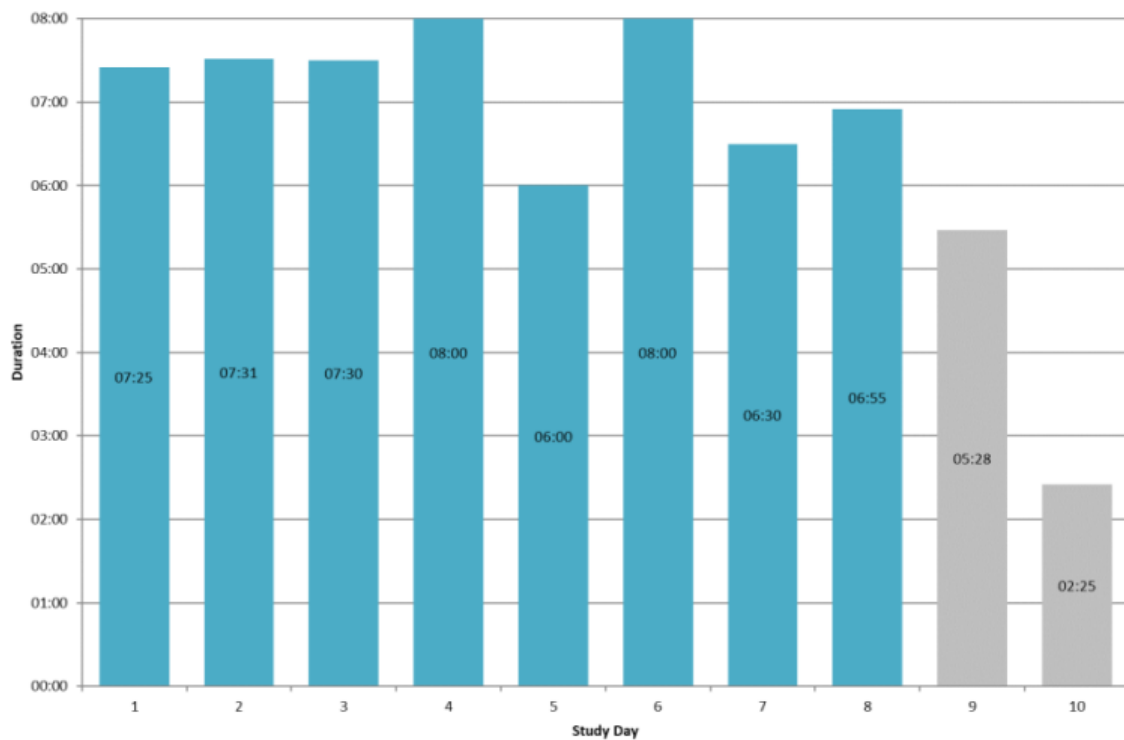**Figure 1 - Case study 1, session durations, start and finish times**

Figure 2 - Case study 1, total study daily durations

From these charts, it can be seen that there was some variation in the duration of study days and sessions. The longest day was eight hours, the shortest (HAZOP) day was six, and the mean was seven hours thirteen minutes. (This is discounting the greyed out LOPA days.) In terms of individual sessions, the mean was three hours thirty-six minutes, with a maximum and minimum of four hours fifty minutes and two hours five minutes respectively.

It should be noted however that these timing data do not take account of short breaks taken within sessions. There was at least one break in each individual session; no data were recorded on these, but they were approximately ten to fifteen minutes in duration each. Another feature of note is that the fifth and tenth day of study, the two Fridays in the period, are

seen to be significantly shorter working days. This is an artefact of the office culture in which the study was conducted, where Friday is always the shortest day of the working week. This may be indicative that straight statistical analysis of the data set may be misleading.

Having stated this, there does appear to be a decreasing trend, both in the day length and session lengths during the second week. This may be indicative of the study team starting to get tired, or alternatively, that they are comfortable with the rate of progress and are pushing less hard than in the first week when there was more remaining to be accomplished.

Because timing data were only taken at start and end of each day, without reference to how much progress through the study had been made, it is impossible to make any statements regarding the acceleration or other behaviours regarding rate of progress, only the total for the study as a whole. The study covered 24 nodes in a total study time of approximately 58 hours, meaning that each node took on average time of 2 hours 25 minutes to study. Similarly, 71 drawings were covered, at an overall average rate of 8.875 drawings / day or an average of 49 minutes per drawing.

Case Study 2

This study was a four-day long workshop. The first day was spent entirely on non-FSHR work, consisting of presentation material and unstructured discussion; this was followed by a two-day HAZID. Then the final day was spent on a related gap analysis study. The HAZID study reviewed a number of items of subsea equipment for use in subsea well emergency response. The scope was largely developed around preliminary operating procedures and field layout drawings detailing the way that the equipment was planned to be used to respond to subsea well blow-out scenarios in shallow water.

The study was completed in the UK, with a very large study team incorporating French, Italian, Norwegian, British and American individuals from a number of different major international oil companies. Attendance was high throughout, with a total of nineteen people present on the first day of HAZID, and eighteen on the second. These numbers were inclusive of facilitator and a dedicated scribe. The study was recorded in Microsoft Word worksheets.

A very large number of drawings and documents, including presentation material as was used in the first day of unstructured discussion, were referenced. It was not possible to establish an exact drawing count. Nine nodes were assessed during the two days of HAZID study in which fifteen and a half hours of study were completed. This resulted in a total of 287 distinct line items being assessed; 25 recommendations were raised during the study.

This study was conducted during the early stages of development of a quantification methodology. It was known from the experience gained in Case Study 1 that more granular data were required to allow information on the rate of progress of the study to be established, but only a very crude method was adopted at this stage, which consisted of noting down time checks and the line item position at that time, as well as the total number of recommendations raised at that time. This was done whenever possible as the study progressed. From these data, which includes start, stop and lunch times, the same charts as were developed for Case Study 1 can be presented, as shown below.
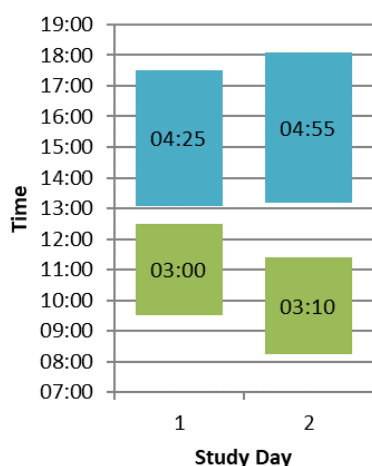

Figure 3- Case study 2, session durations, start and finish times
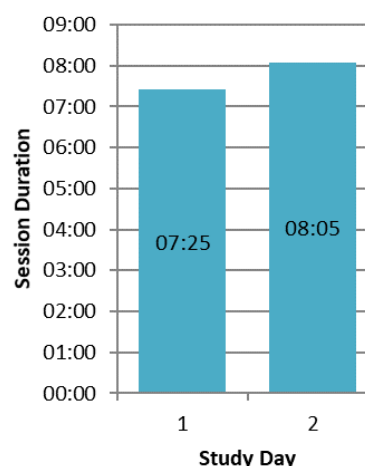
Figure 4 - Case study 2, total study daily durations

Using the additional information provided by recording additional data points within the study, not just start and end points, new graphs can be drawn showing rate of progress through the study. These graphs are produced from the calculated rates of progress and action generation respectively by the following process:

- Input data are – Time, line item number completed at that time, total number of actions raised at this time.

- From the time stamp and the preceding time stamp, a duration is established. By the same process, a number of line items covered and new recommendations raised in this duration is found.

- Dividing the number of line items and recommendations by the duration yields a rate. These rates can then be graphed as line plots showing this rate as the study progresses.
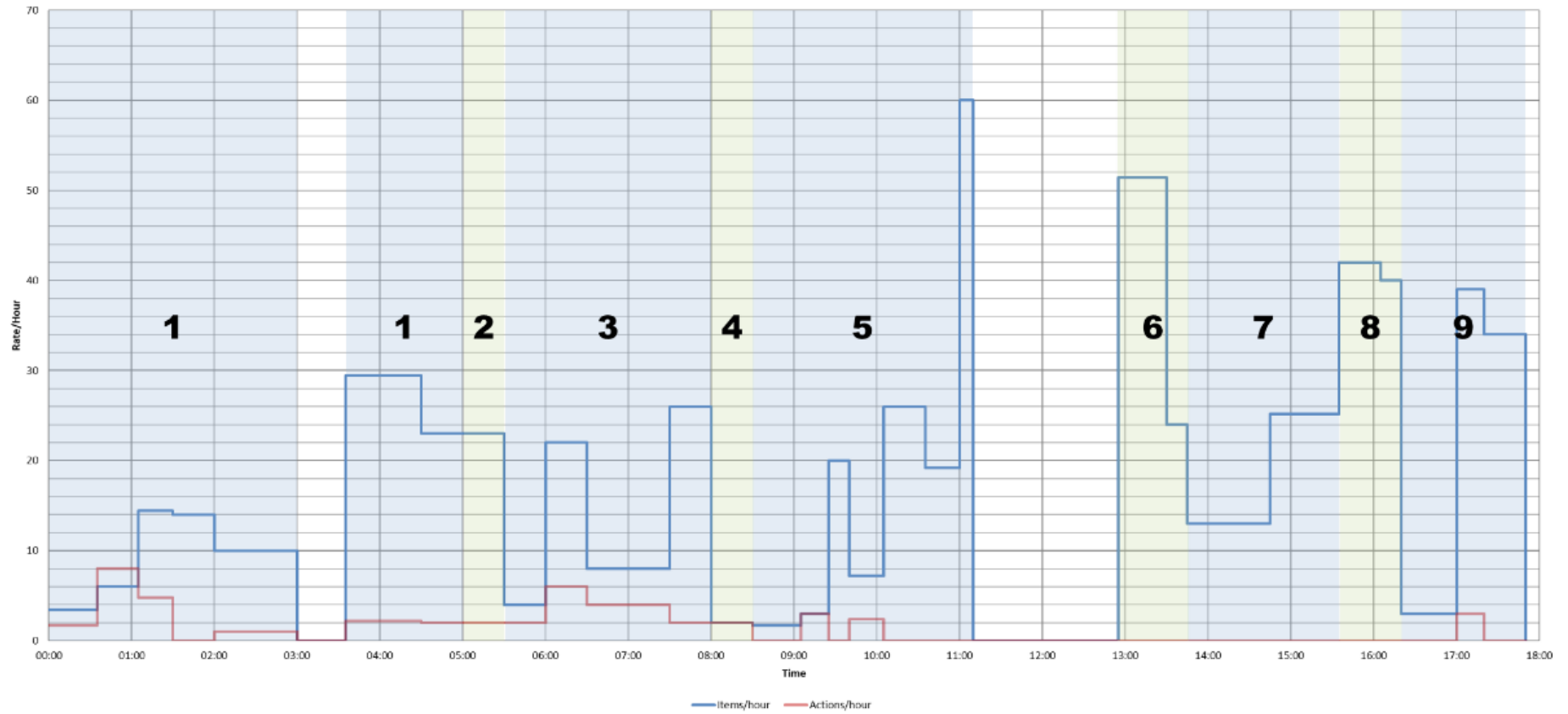
Figure 5 - Case study 2, combined rate chart with node overlay

The resultant graph shows the changing rate of progress of the study as it is completed. The width of the plateaus on these line graphs show the points at which a time stamp was taken and a new rate value can be established. As can be seen there is inconsistency in how frequently these time stamps were taken. This reflects the fact that this was the first time the process was attempted. It was found to be hard to remember to timestamp at a suitable frequency, given that the primary focus of the facilitator was obviously in managing the study. An additional overlay (coloured and numbered shadings) can be provided, which adds to the information presented. This overlay shows the start and stop of each node, as well as when lunch breaks occurred. The resultant chart is shown in the figure below. It should be noted that the break between the first and second day of study lies at the line between node three and node four. The white breaks, where both rates drop to zero, are the lunch breaks each day. The lunch break on the second day is particularly long because an additional non-HAZID presentation was given, taking an extra hour.

Case Study 3

This study was a two-day long HAZOP. The review scope was an unmanned wellhead platform (UWP) in the North Sea, consisting of both production wells with gas lift and water injection wells with the possibility of gas injection. The UWP would be one of a number supported from a conventional field centre platform.

The study was completed in the UK, with a study team composed of British, Norwegian and Spanish personnel. The attendance was fourteen for both days of the study, inclusive of a facilitator who also self-scribed the study in Microsoft Word Worksheets.

A total of thirteen P&IDs were studied, of which nine were process P&IDs and four were utilities. Five nodes were arranged across these drawings. In total, 218 individual line items were created, inclusive of line items noting lunch breaks, other breaks and interruptions to the HAZOP process including time spent describing and discussing at the start of each node. 25 recommendations were raised. A full quantification process was exercised on this study, with line-specific timings input via macro and value data abstracted from the study report afterwards. The quantified data developed from even this short two-day study represent a very large quantity of information. For the first time, line specific timings are present throughout and line values are also represented.

Dealing first with the basic total duration data, these values can now take into account interruption from short breaks and are sensible to the difference between node discussions prior to the commencement of study and the actual line item generation itself. The mean total study duration was 7:55; the mean working duration was 6:36 while the mean actual time spent on HAZOP line item generation was 5:48 per day.

Table 3 – Case study 3, duration data

Description	Duration
Total study (Start to finish, inclusive of interruptions such as lunch and node review)	15:49:08
Day 1 total study	8:02:10
Day 2 total study	7:46:58
Total working (excluding all breaks and lunch but inclusive of node description time)	13:12:38
Day 1 working	6:47:14
Day 2 working	6:25:24
Total HAZOP (only HAZOP line items)	11:35:15
Day 1 HAZOP	6:14:21
Day 2 HAZOP	5:20:54

It is perhaps surprising that so much time in a HAZOP meeting is actually spent not completing FSHR line items – over two hours out of each working day in this study. The value is particularly low in the second day where the need to stop and discuss three nodes (two were covered in the first day) cut into the available time for line item generation. However, it must be recognised that time spent on the description of a node and the alignment of the team on the scope being covered does yield benefit in increasing the rate of progress once the FSHR process itself starts.

At the macro level, it is also possible to establish a true overall mean rate of line item progress. Of the total 218 line items, 201 were actual HAZOP line items (with the remainder detailing E and F type line items, i.e. breaks, node description etc.) Dividing the total number of line items by the total HAZOP working time gives an average rate of 17.3 line items per hour. Other high-level data available at this point includes the overall distribution of line item types.

Table 4 – Case Study 3, distribution of line item types

Code	Line item description	Number of line items created	Percentage of A-D code total
A	Novel, fully developed hazard	104	52%
B	Partially original content, with some copying or duplication	26	13%

Code	Line item description	Number of line items created	Percentage of A-D code total
C	Cross-reference to existing item	45	22%
D	Statement of negative outcome (i.e. no hazard identified)	26	13%
E	Pre-node description and discussion	5	-
F	Non-line item duration e.g. break, lunch etc.	12	-
	Total	218	201 (A-D)

This shows that just over half of the total HAZOP content consists of fully developed hazard scenarios, with about a quarter being partially original content and the remainder made up of cross referencing and statements of negative outcome.

By further analysis of the line item data, a complete timeline of each day can be rebuilt, showing the actual progression of the study through different activities, as shown in the tabulation below. From these data, a more detailed version of session duration, start and finish time chart (as was presented for case studies 1 & 2) can be created.

Table 5 – Case study 3, session timeline

	Start time	Description	Duration
Day 1	09:06:56	Node 1 description	00:09:25
	09:16:21	HAZOP Node 1	00:44:03
	10:00:24	Break	00:11:16
	10:11:40	HAZOP Node 1	00:08:12
	10:19:52	Interruption	00:05:01
	10:24:53	HAZOP Node 1	02:03:07
	12:28:00	Lunch	00:29:49
	12:57:49	HAZOP Node 1	01:21:34
	14:19:23	Break	00:16:50
	14:36:13	Node 2 description	00:23:28
	14:59:41	HAZOP Node 2	00:47:28
	15:47:09	Break	00:12:01
	15:59:10	HAZOP Node 2	01:09:56
	17:09:06	Finish day 1	-

	Start time	Description	Duration
Day 2	08:42:42	Node 3 description	00:13:23
	08:56:05	HAZOP Node 3	01:04:36
	10:00:41	Break	00:13:48
	10:14:29	HAZOP Node 3	00:39:42
	10:54:11	Node 4 description	00:14:28
	11:08:39	HAZOP Node 4	00:41:42
	11:50:21	Break	00:11:00
	12:01:21	Node 5 description	00:36:39
	12:38:00	Lunch	00:44:59
	13:22:59	HAZOP Node 5	01:14:57
	14:37:56	Break	00:11:47
	14:49:43	HAZOP Node 5	01:39:57
	16:29:40	Finish day 2	-

These data result in a much more comprehensive view of the studies progression and allow the creation of a powerful visualisation (See figure 6) showing the real activities that have made up the duration of the study. From this it can be intuitively established how the study has progressed.

If such was required this kind of visualisation could be expanded to identify nodes worked, and supplemented by time data labels. Even in this clean form it provides an immediate view of the way the study happened. The second short break on the first day (an undesired break caused by the late arrival of a group of attendees) can be seen, as well as the unusual decision, after a break on the second day, to prepare the final node but then stop for lunch before beginning the study work.
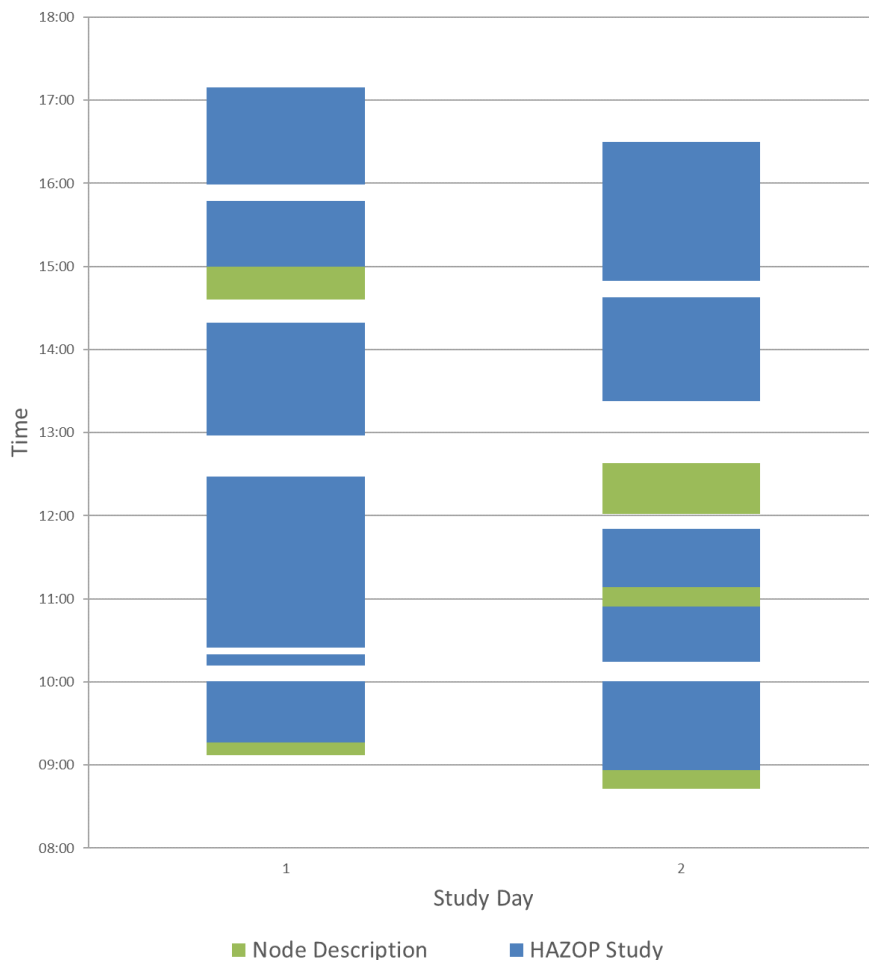
Figure 6 - Case study 3, study timeline visualisation

It is interesting also to note that the least time was spent on the definition and discussion of the first node prior to starting study. Perhaps this was because the team was eager to get into the study proper, but it may have contributed to the long duration of the first node. Further alignments can be made, showing time spent on each node and node description activity as shown in Table 6 below.

Table 6 – Case study 3, node and node description durations

	Node description duration	Node study duration
Node 1	00:09:25	04:16:56
Node 2	00:23:28	01:57:24
Node 3	00:13:23	01:44:18
Node 4	00:14:28	00:41:42
Node 5	00:36:39	02:54:54

These data can be compared against the assertion of Dunjo et al [Dunjo, 2011] that the first node takes double the time of the rest. Here the first node took 4:17 versus a mean for the remaining nodes of 1:50. This complies quite closely with their estimation methodology.

Now turning to rate based data, two key graphs can be developed showing the rate of progress and rate of value generation. This moves on from case study 2 where only recommendation generation rate was available, folding in the extra information regarding the type of each line item to generate a more comprehensive value metric.

Figures below show the rate of progress and rate of value generation respectively for the study as a whole. An overlay is present showing the position of the nodes. These two charts are showing the overall picture for the study. It would be possible to refine the view focussing on an individual node, and implementing an overlay demonstrating the breakdown of HAZOP parameters within the node.
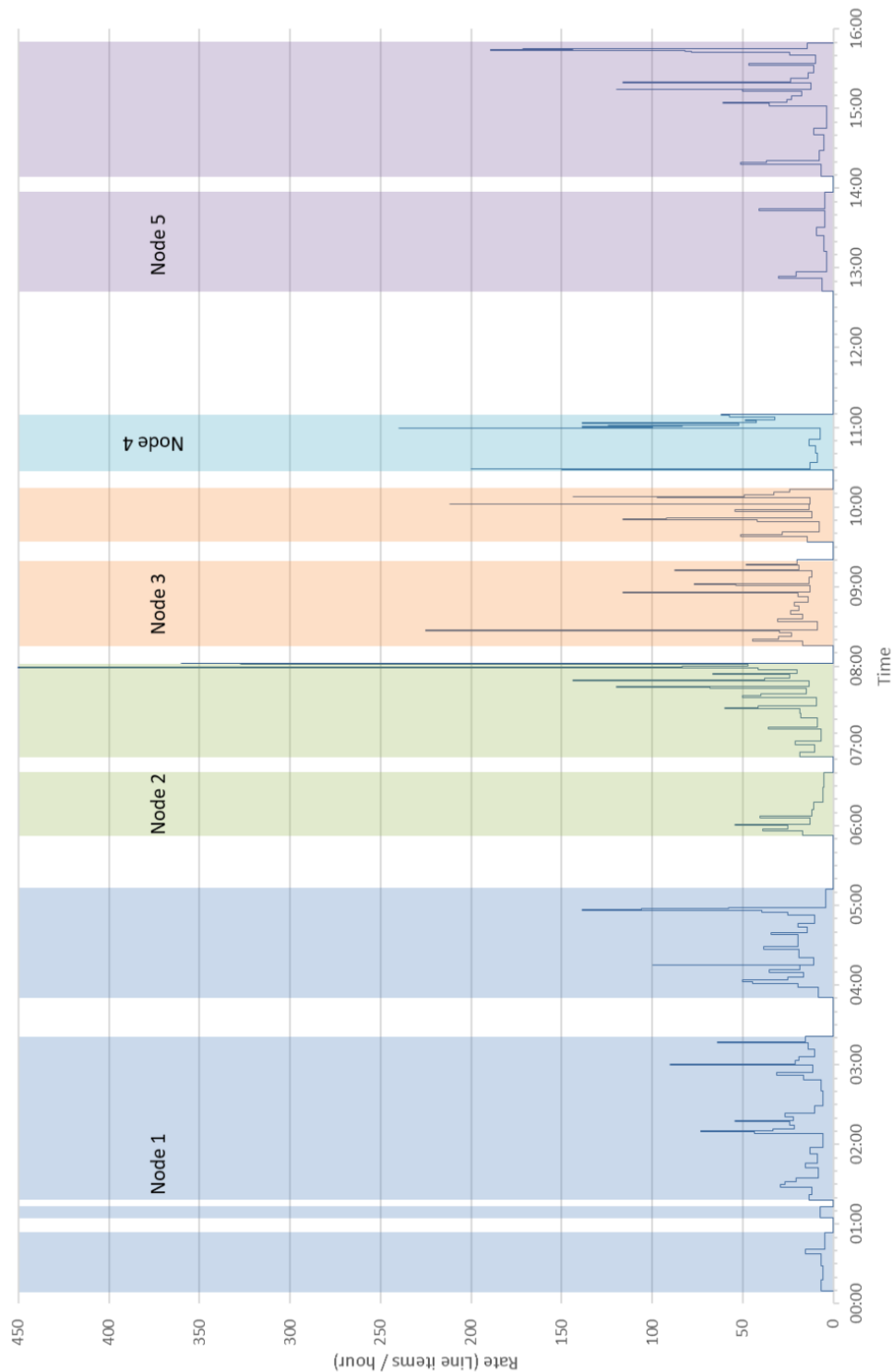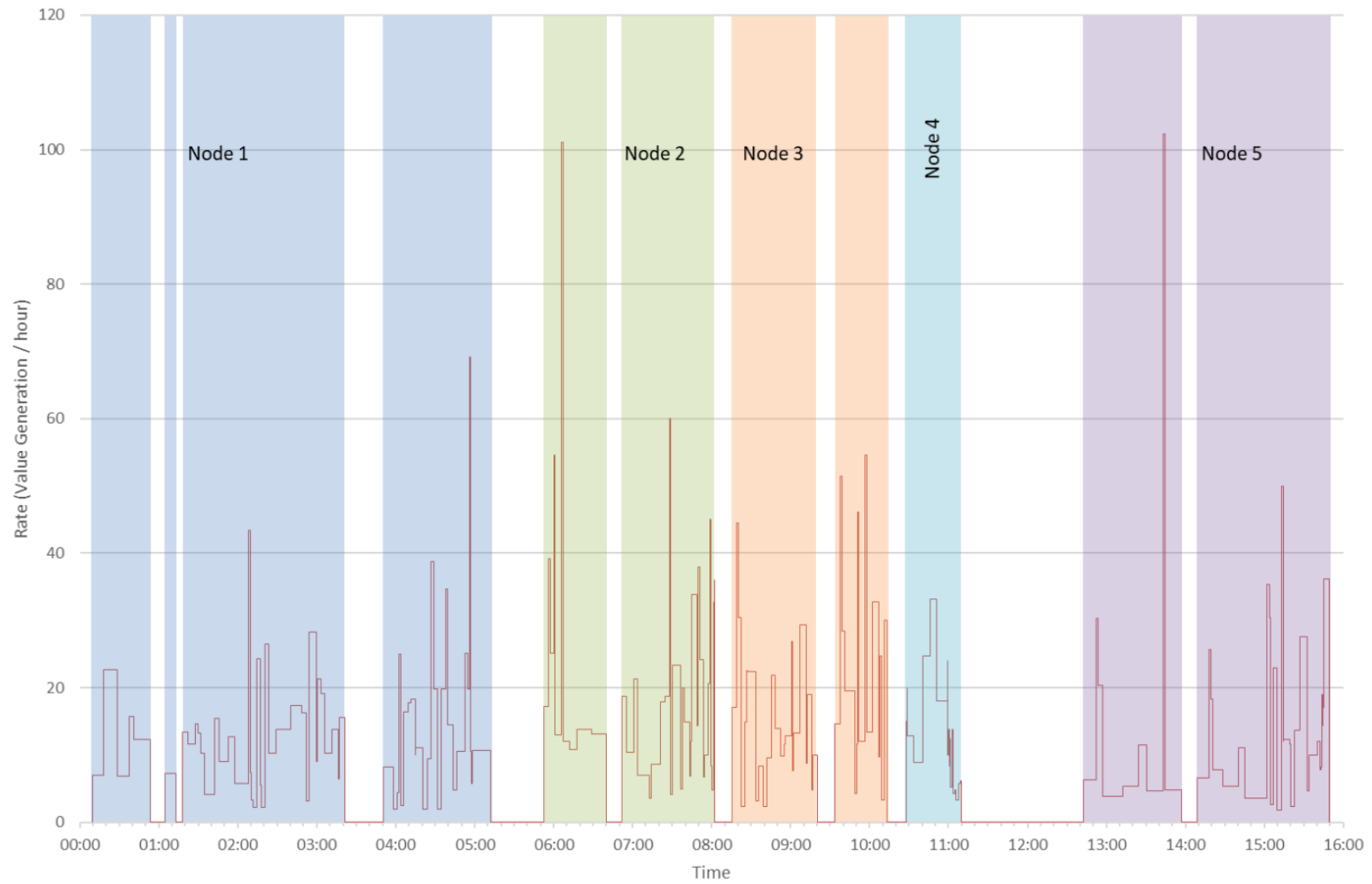
Figure 7 - Case study 3, rate of progress

Figure 8 - Case study 3, rate of value generation

Conclusions

Case Studies

The case studies presented have been selected to demonstrate:

- the information position prior to the implementation of quantification,

- some of the developmental process worked through in coming to a finalised methodology, and

- the end result of the application to a study of the selected methodology including all features.

The final case study has demonstrated novel data being developed, and has showcased visualisations of these data which provide new insight into the underlying process. At this stage, the methodology proposed is considered to be suitable for testing by other parties, as part of live FSHR work in industry. Further development and testing will undoubtedly refine the methodology further.

The case studies have also led to a number of areas where the hypotheses derived from the survey data can be compared. Insufficient data are present to go about proving or disproving any theorem, but statements can be made regarding the alignment or lack of alignment with these tribal knowledge expectations. The alignment found between the case studies and the hypotheses developed from the survey is shown in summary below.

Table 7 – Summary of case study outcomes in relation to hypotheses

#	Hypothesis	CS 1	CS 2	CS 3
1	The rate of progress measured as line items per hour is expected to increase as a study progresses.	No comparison possible	CS demonstrates increasing rate	CS demonstrates increasing rate
2	The rate of value generation may demonstrate a trend differing from the base rate of progress.	No comparison possible	Slow initial rate was combined with high initial rate of recommendation creation	CS demonstrates relatively consistent rate of value generation, despite increasing rate of progress
3	The average duration of study day should be six hours and ten minutes.	CS duration longer at 7:13 including breaks	CS duration longer at 7:45 including breaks	Mean working duration 6:36, of which 5:48 spent completing FSHR line items
4	The rate of progress or rate of value generation may be affected by study days running longer than six hours and ten minutes.	No comparison possible	No visible effect	No visible effect
5	HAZOP should cover 4.2 process P&IDs per day.	CS rate higher at 8.9	No comparison possible	CS rate higher at 6.5
6	FSHR studies will proceed with higher rate of progress through less complex drawings.	No comparison possible	No comparison possible	Simple UWP P&IDs may explain high rate

A number of features should be highlighted. Firstly, that increased levels of quantification increase the number of data-backed statements that can be made about a study. This is shown in that case study 1, prior to quantification, can only address two of the hypotheses, while case study 3 can address all to some extent.

Secondly, the individual hypotheses can be considered in the light of the Case Studies' findings. Both CS 2 and 3 demonstrate increasing rates of progress; the position regarding rate of value generation is less clear. All three case studies show day durations longer than expectation; however, no visible effect was seen regarding overly long days. Both HAZOP case studies showed P&ID rates higher than expectation. Further information would be required to establish if this was due to Utility P&IDs and other simple drawings.

Methodology

In considering the potential benefits and disadvantages of the proposed approach, respect should be given to Goodhart's law. This hypothesis, formulated by economist Charles Goodhart can be stated as, "When a measure becomes a metric, it ceases to be a good measure", or, "Any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes."

This highlights that, while the application of metrics is a powerful tool in conforming and managing processes for improvement, it must be wielded carefully, such as to yield the desired effect without unintended consequence. This ties in to the point raised in the introduction that the focus of improvement in FSHR practice must be to do more with less, not just do the same thing in less time. The development completed during this study has established a firm basis for a novel methodology feature which can be implemented in FSHR practice.

Three case studies are presented, with varying degrees of quantification data. The first study includes only very basic session duration timing data. The second is a developmental study where quantification processes were first trialled in a coarse manner. The third study is a fully quantified example incorporating the features of the defined methodology.

The final case study, a HAZOP, was fully quantified including line-item specific time stamping and value coding information. This study was able to demonstrate significant new levels of information regarding the way the study progressed and associated metrics. This was demonstrated through improved visualisations.

Consideration should be given to future works, and a number of potential fields have been identified. These begin with the development and collection of larger quantities of data by propagating the methodology to industry, to allow more studies to be subjected to quantification. Once large amounts of source data are available, analysis of the process, and subsequent process improvement can begin in earnest, targeting areas where data-driven changes can yield improvements in quality of studies and the safety of end designs.

Other areas where future research and development may be fruitful include potential applications of quantification data and visualisations in FSHR training, particularly in addressing the needs of facilitators to develop and continuously improve. Similarly, the data available through quantification may be able to drive improved and refined methodologies for the estimation of FSHR study durations. Finally, there may be found to be ways for software development to aid the process of data acquisition, and to fold quantification into more far-reaching semi-autonomous / "intelligent system" developments of FSHR recording software and scribe support tools.

It is hoped that further studies will be completed in the future, building from the developments made here to realise the possibilities that this investigation of the quantification and analysis of FSHR has revealed.

Acknowledgements

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