Forecast quality improvement with Action Research

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International Journal of Forecasting

DOI:
10.1016/j.ijforecast.2018.02.005

Published: 01/03/2019

Peer reviewed version

Forecast quality improvement with Action Research: A success story at PharmaCo

Abstract

There is a gap in forecasting research surrounding the theory of integrating and improving forecasting in practice. The amount of academically affiliated consultancies and knowledge transfer projects taking place, due to a need for forecast quality improvement, would suggest that there are many interventions or actions taking place. However, the problems surrounding practitioner understanding, learning and usage are rarely documented. In this article we make a first step in trying to rectify this situation by using a specific case study of a fully engaged company. A successful action research intervention in the Production Planning and Control work unit improved the use and understanding of the forecast function, contributing to substantial saving, enhanced communication and working practices.

Keywords: Action research, forecast quality improvement, supply chain forecasting, forecasting practice, information sharing

1. Introduction

'*Forecast quality improvement remains a barren field'* (Fildes & Petropoulos, 2015).

There is a long-standing gap in research regarding day to day forecast use, and how to improve it (Fildes & Hastings, 1994; Fildes & Petropoulos, 2015; Mahmoud, DeRoeck, Brown, & Rice, 1992) which we need to understand in order to integrate academic forecasting research. While it would appear that more companies are using statistical forecast support systems (Fildes & Petropoulos, 2015) there are still issues surrounding training, perception and understanding of the impact of demand forecasting throughout the production and supply chain (Moon, 2006).

Forecasting in practice is a socio-technical system involving humans, established processes and computers. Decisions regarding forecast use are often made in a dynamic environment but the processes surrounding them tend to be prescribed systems, developed over time and specific to the individual company. Action research is a paradigm which studies interventions in real world practices aimed at improvement and/or change (Baskerville & Wood-Harper, 1996a; Eden & Huxham, 2006; Lewin, 1946; Susman & Evered, 1978). It provides a framework that can explore the standard use of forecasting in practice alongside the barriers to implementation and the behaviours surrounding forecast understanding and use. It requires iterative development, is forward looking, collaborative, situational and implies system development (Susman & Evered, 1978), it has also been recommended for use in studying and managing change in socio-technical systems (Mumford, 2006). The use of forecasting in a supply chain context is likely to be different for each organisation. If we aim to improve forecasting support systems, then we must audit current systems and move towards an *idealised future state* (Moon, Mentzer, & Smith, 2003). This makes action research an ideal method to aid and study forecast quality improvement through the utilisation in practice of academic research and algorithms.

Moon (2006) and Fildes & Petropoulos (2015), outline methods that can be used to help improve the forecasting function in an industrial setting, but not a clear set of recommendations for improvement interventions. How do we move beyond performing a forecast audit (Moon et al., 2003) to go onto the idealised future state, especially if we are unable to persuade a company to employ and/or train a forecast champion?

There is a growing body of work related to behaviour in forecasting: to name a few notable examples cited in the literature Kreye, Goh, Newnes & Goodwin (2012), Kremer, Moritz & Siemsen (2011) and Makridakis & Taleb (2009) investigate reactions to uncertainty; Lawrence, Goodwin, O'Connor, & Onkal (2006), Fildes, Goodwin, Lawrence & Nikolopoulos (2009), Goodwin, Onkal &

Thomson (2010) study the effect of judgmental adjustments on statistical forecasts. What many of these papers have in common is using either experimental observations or empirical evidence (or both) to build theory concerning behavioural effects. What has not been covered are theories concerning interventions in practice to improve forecast systems, for this methods which view relations and interactions between the social and the material are necessary, see Cecez-Kecmanovic, Galliers, Robert, Henfridsson, Newell & Vidgen (2014) for a review with respect to information systems research.

What paradigms should we use in order to study, and successfully perform, forecast improvement such that we can learn from each other's interventions and advance theory? For this repeatable holistic methods are required which are able to capture all of the nuances of a complex socio-technical system. This theory already exists within Organisation Science (Argyris, 1970, 1977; Orlikowski, 2000; Sandberg & Tsoukas, 2011) and Operations Research (Jackson, 2003; Mingers & Brocklesby, 1997; Ormerod, 2014a) but to date has not been developed within forecasting research. We contribute to forecasting research by describing an action research project which has improved the use and perception of the forecasting function in a multinational company; this is, to our knowledge, one of the very few studies - if not the first[1] one - that have been undertaken explicitly using action research in order to improve the supply chain forecasts.

Oliva and Watson performed a series of qualitative studies (2009, 2011) in sales forecasting and supply chain planning. This was done via employing state-of-the-art qualitative techniques that are not often seen in the forecasting literature. Based on the original work of Eisenhardt (1989), an intensive case study research approach was conducted through the analysis of 25 semi-structured interviews and observations of two meetings (Oliva & Watson, 2009). Following that, an exploratory study was implemented (Oliva & Watson, 2011), that developed propositions which formed the basis of further theoretical elicitation derived through a grounded research approach (Glaser & Strauss, 1967). They found that consensus approaches help to break down functional biases but

[1] This claim is evidenced by an extensive search with the term "action research" in all past articles in the two flagship specialist forecasting journals: the *International Journal of Forecasting* (through Elsevier ScienceDirect) and *the Journal of Forecasting* (through Wiley Online). This search brought back only five and one articles respectively and after a further careful read these articles have not employed action research as the methodological research framework. The claim is further substantiated through anecdotal discussions with IIF members during the last three IIF symposia as well as the editors of this special issue that attest that there is a very limited body of operational forecasting research conducted in a non-positivistic approach. There are however studies employing Action Research in a *Foresight* context, predominantly published in the *Journal of Technology Forecasting and Social Change*, but yet again in a very different context from operational forecasting or supply chain forecasting in general. There have also been qualitative forecasting studies with either grounded theory or other similar to AR approaches reported in OR/OM/MS journals: most notably the studies from Oliva and Watson (2009; 2011) and Caniato et al. (2011)

that new biases are inevitable as new co-ordination systems are created in supply chain planning using consensus derived organisational forecasts.

Integrating quantitative and qualitative forecasting approaches has been studied using action research (Caniato, Kalchschmidt, & Ronchi, 2011). This paper was also based on an intensive case study in one company, finding that organisational change, functional alignment and increased knowledge helped to improve forecast accuracy and knowledge consensus. Cross functional alignment was also found to be effective at improving organisational planning around a forecast by Oliva & Watson (2009).

In order to effectively study forecast practice within PharmaCo we have also used intervention theory (Argyris, 1970), and as an analytical lens to understand the evolution of this process, Pickering's Mangle of Practice (Pickering, 1995; Pickering & Guzik, 2008) as adapted by Ormerod (Ormerod, 2014b) for use in OR studies. The mangle is particularly suited to studying the interaction between humans, systems and material objects, such as computer systems and algorithms, and the transitions that these interactions can induce (White, 2016). As we shall see, it could be argued that the whole study was 'mangle-ish' throughout its implementation (Pickering & Guzik, 2008) in part due to the reflexivity inherent in action research studies (Westling, Sharp, Rychlewski, & Carrozza, 2014). The mangle also provides a structure with which to gather recoverable information from the action research data (Checkland & Holwell, 1998; Eden & Huxham, 2006) which can be compared to other forecasting research. This enables theory building regarding forecast improvement and integration.

The research was initiated as part of a joint funded project by a British HEI and a local manufacturing division of a large multinational company[2]. It was aimed at addressing problems of variability reduction with the hope of managing uncertainty in the supply chain. This evolved during the case study into a central question;

How can analytics methods be used to augment the alignment of production with demand?

But first another question had to be addressed;

How is the demand forecast used and mutated through the whole supply chain and how can the understanding of its use be improved?

This latter question was addressed through multiple iterations of action research which allowed a

[2] The research project was undertaken under a non-disclosure agreement. The company has been disguised but all of the information presented is fully accurate.

high level of engagement within the company. As the project unfolded it became clear that action research is a useful tool to help improve understanding of the forecasting function.

2. Methodological review

Since forecast quality improvement is about all aspects of the forecast use and understanding a method is required which allows for participation and reflective learning by any and all practitioners who use forecast information. In the context of Operations Management and Operations Research, action research practices seek to provide a solution to problems faced by an organisation and in so doing become a project within the firm; at the same time there is an academic objective to inform research (Coughlan & Coghlan, 2002; Eden & Huxham, 2006). When applied to messy, ill structured management problems, action research becomes an opportunity for creative design and exploration (Holmström, Ketokivi, & Hameri, 2009; Westbrook, 1995).

Action research's primary requirement is an integrated relationship between the researcher and the organisation. For this reason the position of the researcher must be stated explicitly (Eden & Huxham, 2006). In general, action research will change the path dependence of all of the actors involved and of the intervention itself (Hämäläinen & Lahtinen, 2016). The 'action' in action research implies an improvement directed change which will be specific to the organisation being studied (Susman & Evered, 1978; Westling et al., 2014).

Described as a *'corrective to the deficiencies of positivist science'* (Susman & Evered, 1978, p. 589) action research must be judged by different criteria (Baskerville & Wood-Harper, 1996b; Eden & Huxham, 2006). The evolution of new theory is important (Eden & Huxham, 2006) but so too is the success and permanence of the induced change, the increase in knowledge of the participants and how much the study adds to academic understanding of practice (Baskerville & Wood-Harper, 1996a; Chein et al., 1948; Susman & Evered, 1978). As a sociotechnical system, the supply chain forecast is more than a number that is fed into a production schedule which is judged through an arbitrary accuracy metric (Deschamps, Mello, Gilliland, Tynes, & Jones, 2005). There are also social and cultural issues which can be explored by using holistic methods which allow for opinions and differing worldviews which may or may not change during the action (Checkland, 2000).

Intervention Theory (Argyris, 1970) provides a guide to enabling a successful, practical intervention with clear ethical boundaries;

1. Valid information – the researcher must ensure that the data they collect and/or produce is valid and continues to be so for as long as it is needed.
2. Free choice – this is not a prescriptive exercise. The practitioners must be free to

choose their level of involvement or otherwise.

3. Internal commitment – a consequence of valid information and free choice if the practitioner trusts and believes that the recommendations will serve them and their process well. This step provides closure to enable longevity of the changes induced.

Chein et al., 1948, describe, four types of action research iterations, any of which may be used at any time, in parallel or cyclically, all of which are improvement orientated and feed back into the system under study;

- Diagnostic AR – using data and research knowledge to inform practice
- Empirical AR – investigating the current practice
- Participant AR – both of the above with the inclusion of the participants
- Experimental AR – where the researcher and participants are involved in setting up an experiment in order to take action and study its consequences.

The performance of action research consists of five phases adapted here for use in forecast improvement exercises (Baskerville & Wood-Harper, 1996a; Susman & Evered, 1978) (Fig. 1)

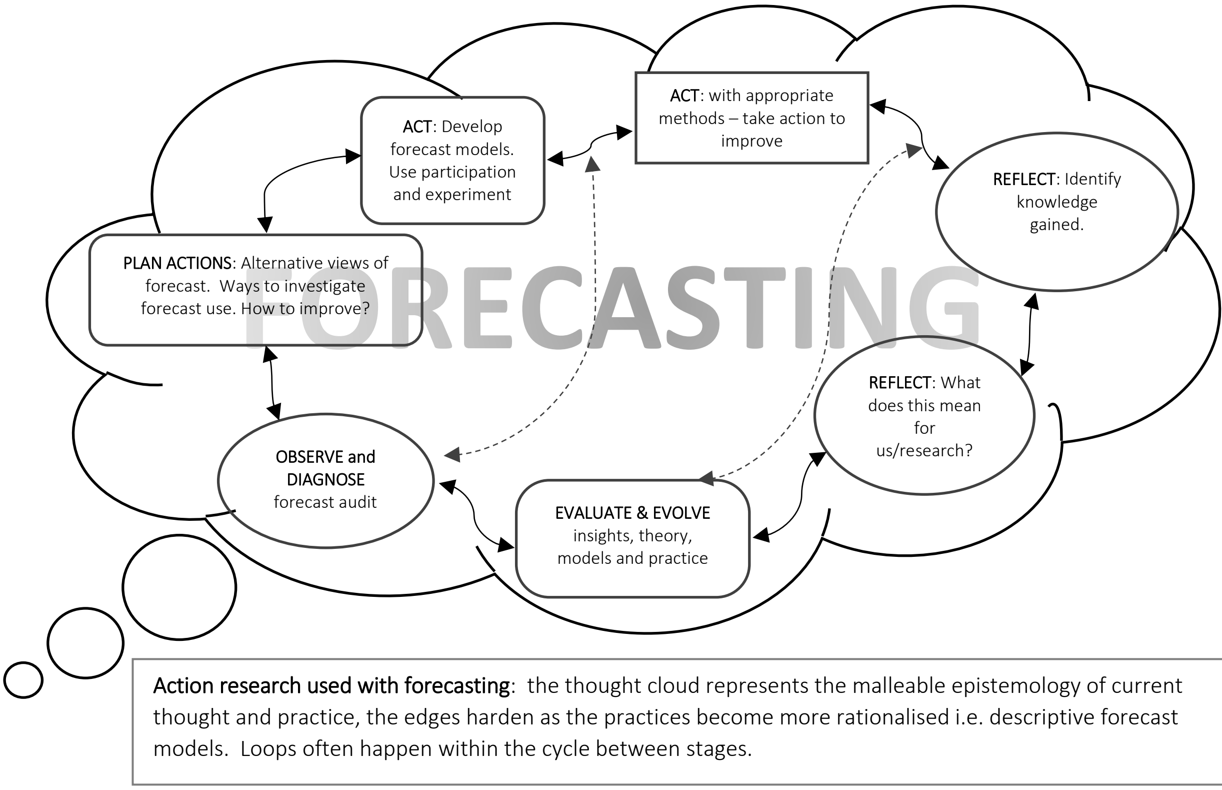

Figure 1. Action research used with forecasting

As theory informs practice ideas and solutions emerge from the process, these become the actions that are studied to produce further ideas and theories. It is a temporally emergent process and this is where the mangle of practice (Pickering, 1995) helps to give a framework to the analysis of findings.

The mangle describes a decentred '*dance of agency'* between all of the players in the action research network. The mangle then studies the interactions and induced changes in the human agents, but also the material artefacts such as computers and the forecasting support software. Also under consideration are the prevailing rules of the system, such as regulatory requirements and the organisational epistemology. The interactions between them set up a network of agency where the role of expert can be taken up by any one of the actors at any time, this is what is meant by a 'decentred' dance. The term actors covers any of the players which may have agency, where agency is taken to mean the facilitation of actions through time.

Ormerod (2014b) provides an outline of adapting the mangle for OR practice to which we would refer the reader. In brief it consists of a full description of agents and agency, the initial intervention idea and how it was changed through practice. Pickering uses the terms;

- *Creating a bridgehead* – a process of bridging from the initial practice to the new, this sets the direction of change.
- *Transcribing* - from the old to the new through disciplined technical agency, e.g. a new software which is learned and put into use, or an algorithm which only an expert needs to understand but which the participants can learn from and/or use.
- *Filling and accommodation* – as new ideas are born and accepted they must be integrated into the existing system. The mangle perspective describes how they are accommodated both systemically and individually. Viewing how the ecosystem of knowledge changes and how relationships between the social, material and the socio-material shift and re-structure as practice changes.

The description of actions through this lens provides a framework for providing recoverable information (Checkland & Holwell, 1998; Eden & Huxham, 2006) which can be compared across many interventions. Each action research intervention is unique but the observations and theory building which emerge can be generalised. These broad boundaries allow accidents and unsuccessful interventions to occur without detriment to the overall findings, and it is partly by knowing what doesn't work that we can learn more about what does (Howick & Ackermann, 2011).

3. Methodology

The researcher spent two days per week studying the company over a three year period and worked for one day per week as a Business Analyst, she will be referred to from here on as CJP. Ormerod (2014b) argues that articles describing case studies should use the first person, but it was felt that the decentred nature of the mangle of practice was best described in this case by giving the human actors names as initials. For this reason the use of acronyms is kept to a minimum to avoid confusion between the human agents and the material or processual agents.

The work was triangulated by using written records of meetings and reactions to events as well as interviews and empirical data. Some ethnographic data was also used as the researcher recorded her own thoughts on a regular basis. Grounded theory was used for the analysis of the qualitative data (Glaser & Strauss, 1967) and since this was an longitudinal case study emergent themes were pursued (Eisenhardt, 1989).

After an initial period of study a proposal was put forward to seek to understand the forecast function as it was used throughout the supply chain. This was to be done using a discrete event simulation model to look at the variation introduced at post production combination testing and quality control. We could then make informed decisions regarding where and how to smooth the process by mapping both the exogenous and endogenous variation.

For the participative simulation we used the PartiSim method (Tako & Kotiadis, 2015) which performs a series of workshops with cross-functional team members. PartiSim requires a modelling team member to be a recorder, keeping a written record of events and reactions, this provided some qualitative data which was added to by use of a questionnaire. The PartiSim technique couples Soft Systems Methodology (SSM) (Checkland, 1999), which is itself a collection of action research type methodologies, and Discrete Event Simulation[3]. The PartiSim was set up following PharmaCo's project management protocols so that it ran as a project within a project. There was paperwork associated with this through which much of the qualitative information generated during the PartiSim workshops was collated. It also enabled the research practice to become aligned with company procedures and for information and learning to be archived for future use within PharmaCo.

The visualisations were developed using Tableau (a proprietary data visualisation software) and R. The statistical modelling was performed in R and the data blending used Alteryx (a proprietary data blending and analysis software). All of the actions using quantitative methods were prompted by

[3] This part of the project will be covered in a future research article.

the reflexive nature of the action research i.e. each mathematical model and visualisation was developed by responding to participant input and from multiple iterations after feedback.

4. The initial conditions at PharmaCo

The company manufactures a complex biological product which is subject to rigorous testing throughout manufacture. In particular when the components are combined into the final kitted product there is a time consuming procedure of quality control testing and documentation.

The initial period of auditing the forecast provided an outline of the physiology of the company's supply chain (Syntetos, Babai, Boylan, Kolassa & Nikolopoulos, 2015);

- **Length:** Finished products were shipped to inventory points and not directly to the customer. In some cases these were then shipped to secondary or even tertiary inventory points. Past sales information was visible at the country level which was then used in an alerts system as described below.
- **Depth:** The forecast procedure used a Middle Out hierarchical structure starting at the aggregate country level across SKUs. Post forecast this was further aggregated across product pack sizes and validated[4] batch sizes for production.
- **Time:** As well as cross sectional aggregation the historical sales were pre-aggregated temporally from the weekly at the monthly level before performing a forecast. The forecast horizon was one month and the average demand lead time was three months. History was visible at the monthly aggregate. There was no categorisation of demand and the same procedure was used on both intermittent and fast moving lines.

The country level forecast was aggregated to produce the feed from an Order Up To (OUT) monthly demand model for the final master production schedule, derived using an Enterprise Resource Planner (ERP) running material requirements planning. This set the production schedule horizon for up to three years to enable procurement planning of some difficult to source raw materials (see Fig.2)

The forecasting software used an extrapolation engine and competed algorithms and aggregations of the monthly, country level (occasionally adjusted) past sales data to find the best forecast from a three year history. Judgemental adjustments were made occasionally and forecast accuracy was

[4] In this industry batch sizes must be validated to adhere to Good Manufacturing Practice, thus reducing the ability to alter batch sizes in production and necessitating defined volume aggregations.

measured against actual sales on a monthly basis. The history was changed manually using simple heuristics but this was not a simple task, due to systemic constraints and a lack of detailed information to hand, so was not performed often.

The forecast system was not to be touched and this was made clear at the beginning of the intervention. We were able to have influence over how it was used and perceived but not how it worked or how the forecast system and resource planner were coupled. This was a limitation on our possible agency.

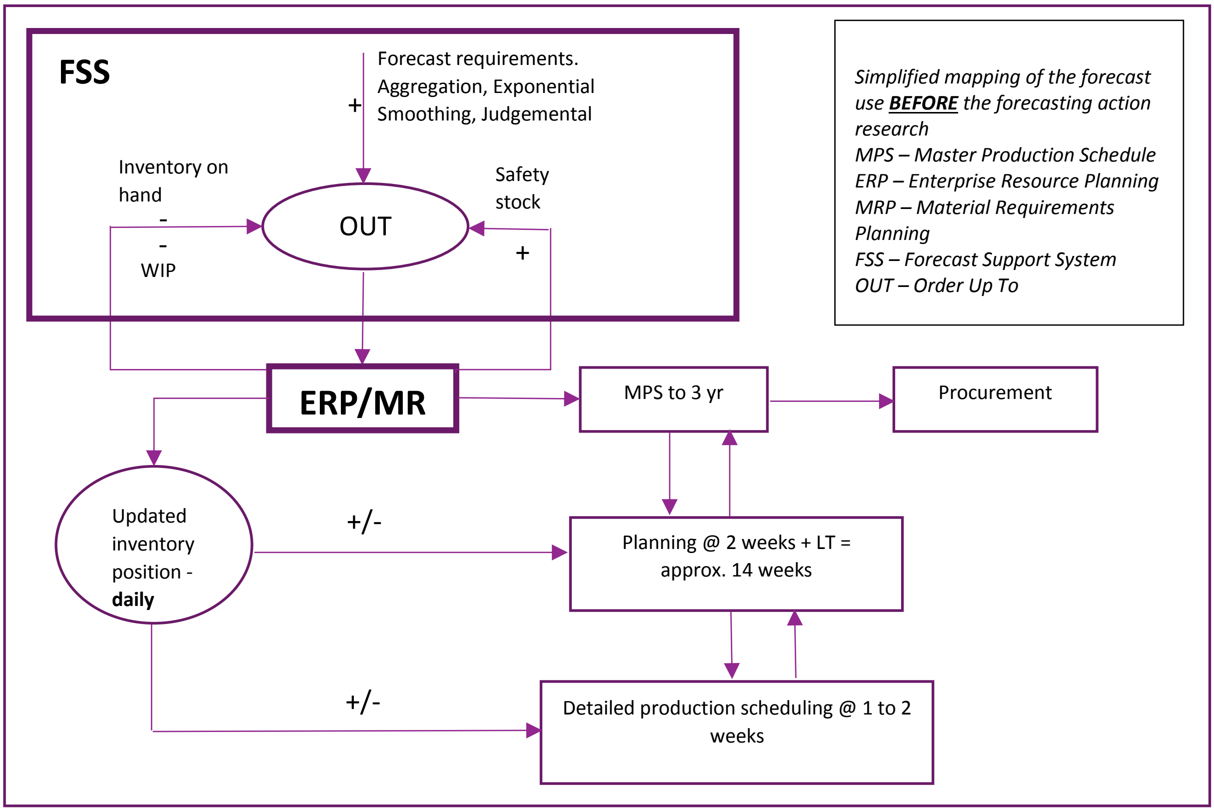

Figure 2. Simplified mapping of the forecast use **before** the forecasting action research

At this time in PharmaCo the forecast was used reactively on a daily basis as the forecast, inventory position, orders and demand information were used to calculate expected weeks on hand. This was collated in something called the 'backorder report' which was used against a SKUs expected delivery date to determine whether an item was at risk of going onto backorder. In this way there was much sharing of demand information along the internal length of the supply chain such that this had material and procedural agency, i.e. the Quality Controllers would use it to prioritise their work and the Planners would use it to adjust the schedule.

The biggest agent of resistance was the way that data was collated and stored in the computer systems. There were other constraints, such as Good Manufacturing Practice (GMP) requirements, which meant that regulatory procedures had to be followed regarding documentation and batch sizing, storage etc. and these could not be changed. Another constant constraint was the busy day to day work of the participants which would often restrict their availability to attend workshops or ability to absorb information. A non-disclosure agreement was part of the contract to work within the company and the recording of events has been self-censured where necessary.

5. The interventions

In early 2014 CJP began work as a contractor investigating demand at PharmaCo. These investigations concluded that the normal sales pattern was flat (relatively constant) when aggregated and that the system of people, processes, software and external supply chain players was overreacting to noise from the sales signal. A project was developed to investigate the viability of smoothing production and fundamental to this was understanding the demand signal and the forecast. A more in depth forecast audit, as diagnostic action research suggested by the Senior Manager (SM) and performed by CJP, was begun.

CJP collated all of the past demand information and investigated every demand spike. A few high demand customers were ordering at regular yet randomly distributed intervals and some demand patterns were comparatively intermittent. This empirical action research began to inform the daily practice of the Demand Planners (DPs) by increasing their awareness of these patterns. The senior manager and CJP worked together on using Individuals and Moving Range (I-MR) charting to identify signal from noise. This was gathered from data stored in the ERP system since it was not available from the forecasting software's historical sales data. It was then altered from individual transactional data to weekly temporal aggregate and a country level cross sectional aggregate with a drill down capacity on lines which had this information. In this way the DPs could be encouraged, through this first action to manage by exception.

By the beginning of 2015 the research into intermittent demand (Croston, 1972; Syntetos & Boylan, 2001) and judgemental adjustments was absorbed into working practice, the DPs were transcribing the knowledge from research by accommodating it within their practice. Judgement was being used less on upward adjustments but maintained on lowering adjustments (Fildes et al., 2009), particularly on the intermittent lines. The Coefficient of Variation came into common use in the department with a good understanding of its instability for low sellers. However the integration of the I-MR charting was resisted by all of the DPs. They could not see how it would work, why did they need sales information at a weekly rate when they created alerts on a daily basis? Here was a resistance to the material agency of the I-MR charting and the processual agency of managing demand by exception. They could not see any advantage in delineating signal from noise or in attempting to define which purchasers were causing sales spikes. They felt they knew who the culprits were and that it wouldn't make any difference as there was no obvious way to integrate the knowledge into their daily working practice.

DP1: *'I just don't see how it will work'*

CJP and the production planning and control manager (PPM) tried setting up workshops and having meetings but other projects were given precedent. If the issue had been forced free will would have been negated and there would have been no internal commitment.

CJP started to collect and analyse weekly data and a new view of the demand profile was emerging. Tableau visualisation software was introduced and this gave insights which had not been available before, a new material agent had joined the dance and was enabling new views of the world through data. DP1 asked if it would be possible to use this view to understand the split in sales between export and local markets with different shelf-life requirements. This action was collaboratively designed as the new Tableau software was transcribed, via CJP's development of data visualisations and the DPs' input, creating opportunities for more actions to improve.

The next step from the sales split was to look at the amount of days which each SKU had available to sell from the DC, again a participant led diagnostic/empirical action. Data were gathered but the blending started to become onerous since matching attribute data with the format from the ERP was not a simple task. Also the cross sectional aggregations across SKUs, countries and, in some cases, customers required data matching across systemic levels which had no obvious connectors. There was a resistance building as CJP tried to get more value from the data systems. The new *'days to sell'* metric was taken up by PPM and introduced to the whole factory, it could be used against the forecast to predict volumes likely to sell and this changed the way that some products were managed. This then reduced variability in the system and contributed to scrap reduction.

While mapping the forecast change through the supply chain a bullwhip effect (Lee, Padmanabhan, & Whang, 1997) became apparent. It appeared that the bullwhip was partly caused by the many aggregation points in the length of the supply chain some of which we had little or no information about. Due to the peculiarities of the product, customers liked to obtain a supply of the same batch for as long as possible and would purchase large amounts of one new batch in preference to an older one. The phenomena was particularly pronounced for supplies to inventory points such as country level warehouses. This behaviour, along with rigid batch sizes and a long lead time, would mean that a bullwhip would always exist (Wang & Disney, 2015). It also meant that the exponential smoothing algorithm that they were often using was biased as it preferentially weights the last observation which could be misleading. This was diagnostic and empirical action research opening up views into systemic effects; when it was mentioned to SM he said; '*I know it's biased I can see it in the figures'.*

The very use of an order up to system has been shown to induce bullwhip (Dejonckheere, Disney, Lambrecht, & Towill, 2003). At this point in time the DPs did not know that their system was an order up to model and it was often difficult to get at the important underlying factors, such as the demand feed. To CJP, demand, meant the figure at the end of the order up to process that was fed into the system on a monthly basis, to the DPs meant the sales history. The maintenance team, who often provided the data, were in another region of the world and IT oriented, generally using a different set of terms in their operating procedures; when they said demand they meant the nightly feed which went between the forecast system and the ERP. They were always willing to help but often at a loss as to what CJP or the DPs were asking for. CJP and SM discussed the possibility of using WIP (Work In Process) and inventory feedback controllers but the information needed for this was not and had never been recorded. This systemic resistance was accommodated by investigating and opening up the different meanings of demand by CJP, aiding a cross functional alignment by having an informed conversation around the different understanding and material representation (i.e. data records), of demand and sales. Since we were performing a reflexive action research we then moved on to other avenues of improvement.

Around the time that the visualisations were being developed it was decided to make further volume aggregations, post forecasting but prior to feeding the demand into the system. It was thought that this would make stocking easier to handle and was part of a drive toward less shipping to improve sustainability. The size had been set close to but just under the size of a batch. One of the Production Planners (PPs) had stated that they thought this was a bad idea as they had seen extreme variance effects from this kind of move before, but they had no rational basis from which to argue their point. At this time systemic noise was masking any attempt to pick out the effect but the master production schedule was becoming increasingly chaotic.

Wang, Disney, & Wang, 2014, show that chaotic non-linear oscillatory effects can easily occur in systems with lead times of two or more forecast periods. This was modelled on a forbidden-returns, non-linear inventory system which allows endogenous feedback as well as exogenous demand variation similar to PharmaCo's system. The extra batching would, in effect, work as a modulus on the WIP term in the demand feed causing oscillatory gain feedback. This was pointed out to the

Production Planning Manager (PPM) using the concept of resonance, resulting in the practice being stopped and the system smoothing. This event provided an opportunity to solve immediate pain and gain trust within the organisation by allowing technical research to have agency.

PPM: *'I get the wave theory and the reality….. I think that we've all underestimated the effect '* email correspondence, April 2015.

While performing diagnostic action research on the demand forecasting and associated processes CJP had bought forecasting/OR discipline to bear in jointly creating new valid information. This transcribed a new view of the world, which had its own agency and was changing the network. The day to day jobs of planners were beginning to change as they started to question and innovate in their working practice by filling and accommodating the new information and tools; Over time new knowledge was incorporated into their working practice (filling) and maintaining the data needed to augment it became part of their routine (accommodation). The changes were easily accommodated since time gained in becoming more efficient was given to data gathering and to scrutinising the visualised information. They were also beginning to come round to the view that demand was fairly constant over the lead time temporal aggregate of three months and that control limits could help them to manage demand.

PPM: *'you showed us the world was flat',* Interview, January 2017

By the Autumn of 2015 the project was entering its second year and the plan was proposed to help smooth production using the PartiSim© method (Tako & Kotiadis, 2015) coupled with modelling of the supply chain forecast to help align production with demand. This would be both a participative and experimental action. In a meeting with senior management, to approve the next stage of the intervention, difficulties faced in blending data were pointed out and software was sourced to help with this. The growing resistance due to the agency of the data storage and collection was accommodated by sourcing appropriate software and building new databases that were fed by the cleansed and blended data. The software needed to be proprietary and well supported, so that it could be maintained after the project finished. It also had to be capable of blending information in a traceable way due to the GMP environment, we chose Alteryx as an easy to use self-service analytics and data blending platform.

The first few workshops gathered information by opening up differing worldviews (Checkland, 1999) on the process of smoothing and what it meant to the actors involved. DP1 stated that; '*items delivered on time and in the correct volumes'* would be smooth for demand planning. While PPs and many quality assurance personnel (QAs) stated that a; '.. *steady …. well mixed ...'* input would be smooth for them. All levels of planning, combination testing and quality assurance were reacting to the backorder report. It was causing re-prioritisation at every stage, working against the established performance indicators, in some cases leading to gaming of the system. This was the first opportunity to realise that all of the members of the cross functional groups were reacting to this report and this resulted in increased variation in the system. The PartiSim was set up to initiate an experimental action but the initial workshops using Soft Systems Methodology (as part of the PartiSim method) had opened up a use of the forecast which none had expected was this disruptive.

The senior management were aware that this report was causing issues and had already suggested that its use might be stopped but this was a difficult subject as staff were wary of not being responsive. The workshops raised awareness of how each section was reprioritising and why. In a feedback questionnaire at the end of the workshop series the highest level of agreement was concerning the learning about other sections needs and practices.

Question	***Mean***	***SD***	***Mode***
Q11: The workshops helped me to know what other departments need.	*5.33*	*0.82*	*6*
Q13: I learnt new things about the way other departments have to manage their processes	*4.50*	*1.38*	*5*

The Likert scale went from 1 – disagree to 6 – strongly agree. The questionnaire was given out to all 10 of the workshop attendees and 6 forms were returned. The question was based on comments made by attendees during the workshop sessions, such as; '*Gives you an idea of the difficulty faced in other areas and ways to help them'.*

By the summer of 2016 the need to develop family groups of items, and to understand what level of aggregation would be viable when smoothing, led to an analytical modelling exercise using the Multiple Aggregation Predictive Algorithm (MAPA) as developed by Kourentzes, Petropoulos, & Trapero, 2014. The MAPA runs Error Trend Seasonality (ETS) exponential smoothing (Hyndman, Koehler, Ord, & Snyder, 2008) on a historical data set over different levels of temporal aggregation, then combines to produce a final forecast. Initially the idea was to look at best aggregation levels for the products. As we moved into the autumn of 2016 and toward the final PartiSim workshops the secondary forecasting part of the project developed and the output was shown to all of the participants in one workshop and in a non-workshop setting to SM and PPC. In this context the MAPA became a model which shone a light onto how forecast usage was inducing variability. It also showed that, contrary to popular perception, there was no discernible trend or seasonality on most of the lines after they were aggregated to production level.

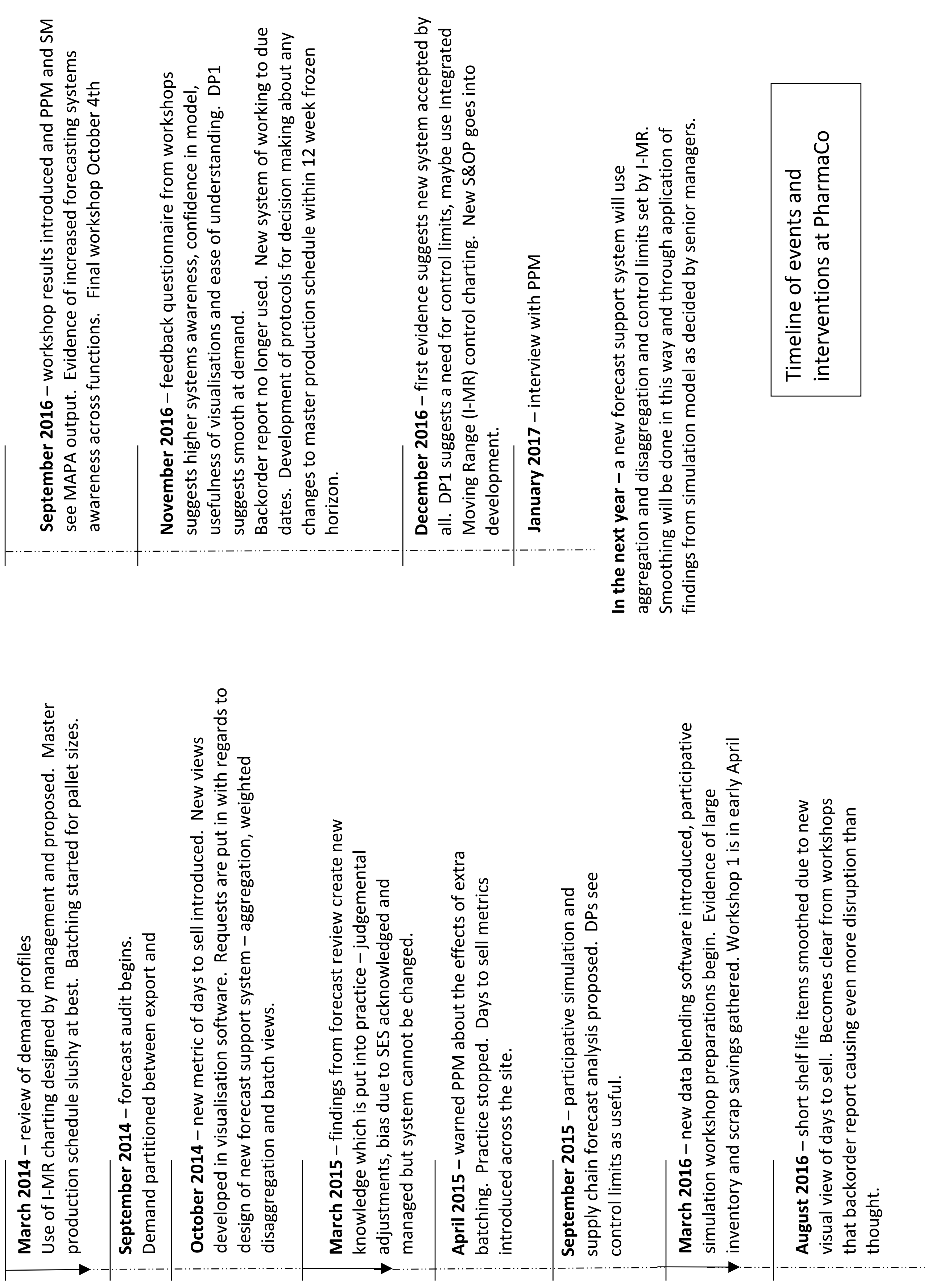

Figure 3. Timeline of events and interventions at PharmaCo

The MAPA was not a perfect model of the system at that time; much of the aggregation was asymmetric, since it was not always aggregated to an exact three month batch size due to validation constraints. Forecast use was also asynchronous, since they were reacting to the daily backorder report to reschedule and using a forecast at many different levels of the planning and scheduling hierarchy which viewed different time spans for their planning. The MAPA did, however, provide a good approximate model of aggregation effects overall and helped to promote understanding of the effects of asynchronous forecast use in the downstream supply chain. In part this was due to the clear visual output provided by the MAPA R package. On one occasion the PPM and SM were shown the MAPA error output in the R graphing window, PPM asked why it was being run on daily data which showed a large error. The answer was; *'because this is what you do when you react to the daily report'*. This was a moment of *'Aha!'* from PPM and *'at last some proof!'* from SM. As the model was run using increasing aggregation buckets the forecast was roughly the same but the error reduced. The forecast model had, therefore, a material agency that, alongside other visualisations, induced rapid change with full internal commitment from those involved.

The agency of the new software coupled with the new data assembly and mathematical models showed how aggregation worked over the sales data as it was aggregated from daily to monthly to quarterly and from individual SKUs to production volumes. This was a diagnostic and empirical action that helped to reassure and provide a material agency that proved much of the internal variation was self-induced. The three month lead time, the pack size splits and more particularly, the daily reaction rate, all smoothed out over the aggregations which was clear to see in the visualisations. The new information view and visualisation were opening up the depth of the supply chain and making it less opaque, a material agency that induced a bridgehead to move toward adherence to the forecast set due dates, rather than a report based on daily data and the average forecast. This was another area of strong agreement in the questionnaire; the visualisations helped them to understand the modelling, and they did not find the modelling hard to understand.

Question	***Mean***	***SD***	***Mode***
Q8: I found the modelling difficult to understand.	*2.67*	0.82	*2*
Q9: I found some of the workshops difficult to understand.	*2.50*	0.84	*2*
Q10: The visualisations helped me to understand what was going on.	*5.17*	0.75	*5*

They were presented with the results of a rolling window CV calculation, cumulative distribution functions, non-parametric histograms, the MAPA forecasting model and a hierarchical cluster analysis. The achieved level of understanding was a surprising result in view of the difficulty of some of these models, since none of the participants were well versed in forecasting or statistical methods. CJP had chosen and developed the models in a reflexive way presenting the results in context, by using appropriate visual models the workshops maintained a behavioural fit. This is an example of data visualisations having a translational material agency, providing insight into processes via mathematical models that were developed using grounded interpretation of qualitative investigations.

The distribution functions provided a way to show differences and similarities in the demand profiles. One QA participant asked ‘*Why is that in different cluster to that? It’s the same product just a different package’.* CJP answered by using these profiles to show that the demand behaviour was very different (see Fig.4) as one was manufactured for a single market. Since the aim was to smooth the system we would have to aggregate the demand over long periods and this was the kind of behaviour that would need to be monitored. The QA had never realised just how volatile some of the demand profiles were until these workshops.   The participative action research was increasing knowledge of the system for all of those involved.

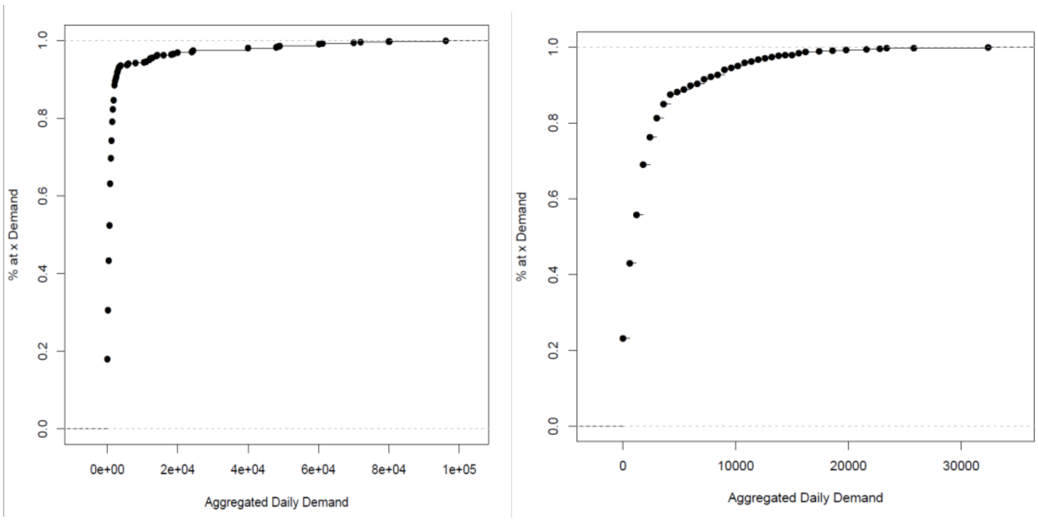

Figure 4: The Empirical Cumulative Distribution Function.

The Empirical Cumulative Distribution Function in Figure 4 may be difficult to explain in lay terms but it is easy to visualise and immediately shows how some demand profiles are very different to others. The graphs below are of the same product but for different countries which have different testing requirements. The harder 'elbow' with less frequent but much larger purchases, in the first graph, is for one country, the company moved to managing this country by exception. The different functions now realised why this needed to be managed differently and became more aligned to this process.

The staff at the testing end of the chain began to see the difficulties of managing demand that was highly variable and to understand the reasons why they were sometimes under pressure to get items dealt with quickly.

QA; '*It's good to hear what goes on in demand and find out why it is like it is'*

They had often thought it was mismanagement or poor forecasting but now realised it was often external effects. Through visualisations of forecasts including confidence bands they also saw how a forecast always becomes more inaccurate as the horizon increases (and the respective prediction intervals wider), this was a phenomena of which they had no awareness. Since their process had a requirement to use a forecast requirement at any point from three months to three years this was valuable knowledge which altered perspectives.

The practice of using the predicted weeks on hand as a daily measure was stopped. Any decision regarding changing the master schedule were now carefully made as a group at the planning level and the plan was effectively frozen at 14 weeks. The quality and testing procedures were now to stick to due dates unless otherwise directed by the planners. The system had changed, through the agency of the simulation and modelling intervention, and it was in a way which had full internal commitment of all of the actors.

In the final questionnaire DP1 stated that any smoothing '*needed to be done at the demand input'*, an improvement on the opinion that smoothing means having *'items arrive on time in the correct quantity'*. The planners accommodated and transcribed the use of the I-MR charting as a way of altering history to give an in control time series on which to base their forecasts. It also provided a way to manage by exception as they used the derived control limits as settings in the existing forecasting software.

6. Results

The change in the way the forecast was used can be seen in Figure 5. Small changes in understanding and practice during the diagnostic phase had profound effects on the supply chain. Large savings on inventory and scrap were achieved through a process of continuous improvement that was enabled by the collaborative action of developing new metrics and views.

By spring 2016 it was estimated that the work had contributed to €4M (see Fig. 6) in inventory saving and a 40% increase in inventory turns. This was due to the participative diagnostic and empirical actions of partitioning of demand, understanding of bullwhip and the days to sell metric. The head count also reduced, by approximately 30% in planning, as workloads eased due to the smoothing effects induced by the work. Following the PartiSim experimental action there was a further reduction of 7% in the overall workforce, which SM put down, in part, to the reduction in churn achieved by the interventions. Production volumes remained the same throughout.

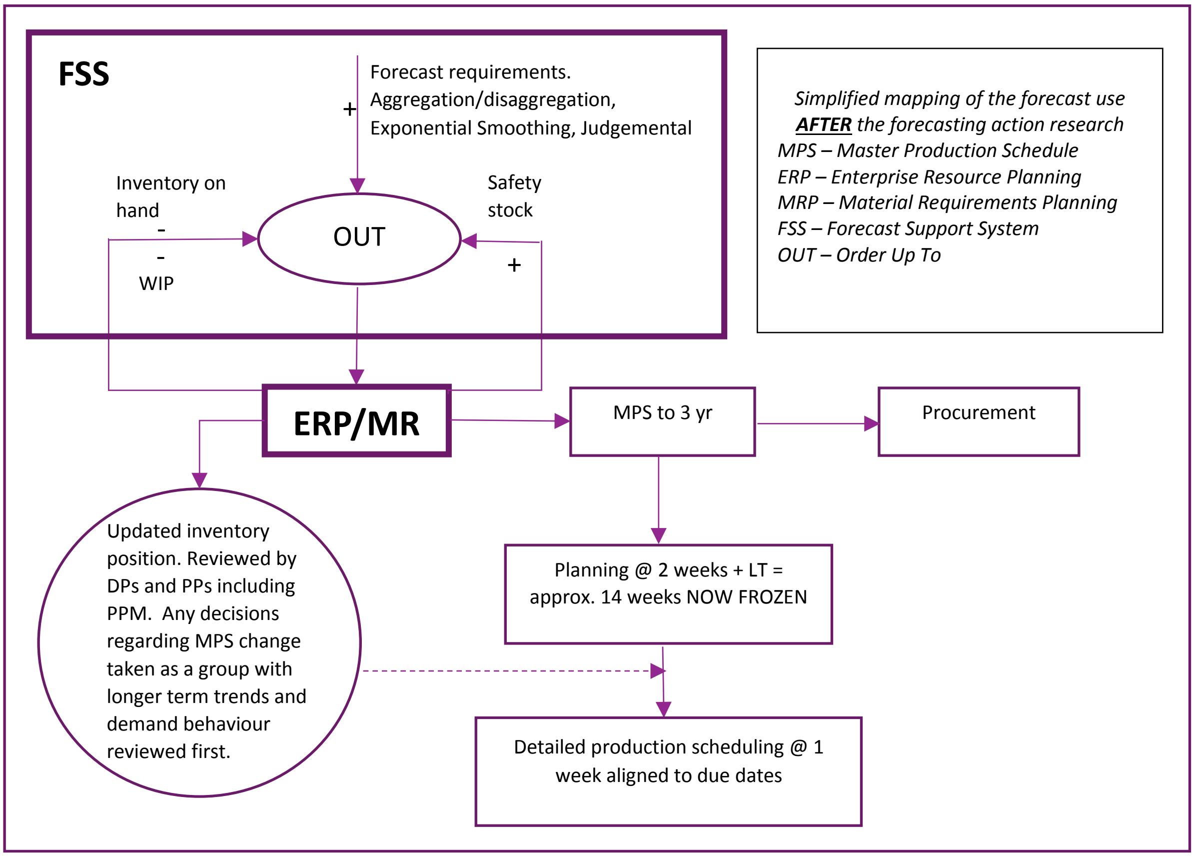

Figure 5. Simplified mapping of the forecast use **after** the action research project

Many companies face issues regarding temporal aggregation due to lead time and delivery constraints but rarely are the batch sizes so constrained and the lead times so long or uncertain as at PharmaCo. In semi-process industries this is more likely to be the case, particularly in pharmaceutical production as these are, in general, uncertain production environments.

The action research facilitated improvement of the forecast use, and the knowledge and communication surrounding it. The production and demand started to align better through reduced variation which has been noted by PPM (see Fig.5 & 7). When asked how the forecast use had changed he said; *'we have an increased awareness of patterns…. Seeing aggregation effects'* and that this had '*increased people's confidence to change things…. We firm the MPS earlier and are not using the forecast for the report any more but due date adherence instead'.* He felt the modelling had '*a significant influence'* in facilitating change, and when asked if anything would not have happened if there had been no interventions he said *'I'm not sure…. Probably would have taken longer….. I think we needed a catalyst for change'.*

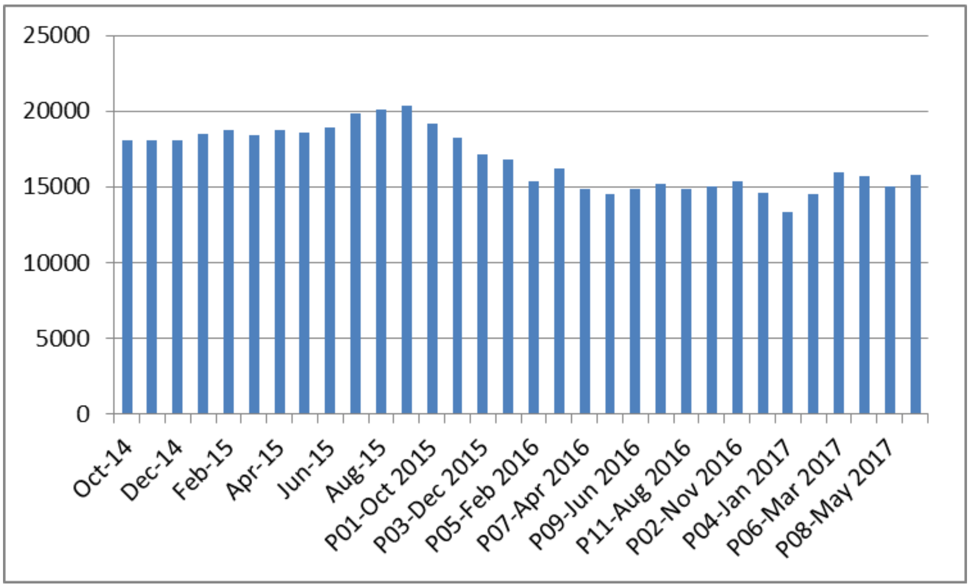

Figure 6. Inventory reduction at the DC's (disguised data). The three month lead time caused the effect of extra batching to be lagged [P0 are financial period for the PharmaCo's accounting systems].

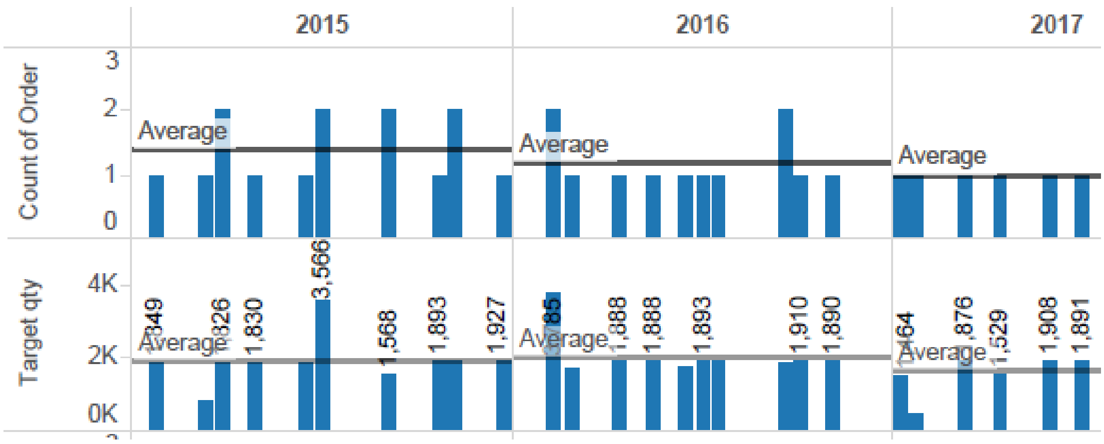

Figure 7. Reduction in internal bullwhip on one line item (disguised data) over time. This phenomena was seen on other lines as well. Note the reduction is in intermittency as well as in volumes. Also note time is along the upper x-axis.

In an interview toward the end of the interventions the Senior Manager noted the most important effect as being that of culture change:

SM: *'just by the interaction with the people themselves it opens their mind to thinking about things that they wouldn't have looked at before.. they would have looked retrospectively … it's opened their mind to thinking 'well if that's what I'm seeing here what does that mean for the future .. in terms of the forecast, what actually is happening', so they're not responding to an event …. It's a fundamental in changing the culture of the site'*

7. Discussion

By using the mangle of practice we can view the social and technical aspects of each of the interventions to improve with the same lens. This allows recoverable information to be gathered which can then be compared against previous research and, in the future, against further research. We have used this to analyse the results of the interventions and gather knowledge from the action research, see table 1 below.

The table shows a common bridgehead of improved forecast use through better communication and enhanced data visibility, that come about as iterations to improve build on each other. Resistance to change is addressed through visualisation of appropriate models that are developed in answer to qualitative data. The qualitative aspects are opened up by the use of action research methods. In a sociotechnical system, such as supply chain forecasting and planning, we need to make use of methods which allow for investigation of the social aspects of a system (Mumford, 2006). In this way a collaborative design process can emerge (Caniato et al., 2011) which increases alignment of the functions (Oliva & Watson, 2011) and breaks down individual functional biases (Oliva & Watson, 2009). The action research was initially started to investigate variability overall and look at the viability of production smoothing, but an emergent effect was improved forecast use and understanding in the supply chain.

The accommodation afforded by all of the actors and their functional processes has a recurring theme of participation building understanding and increasing system knowledge as a cross functional group, allowing the transcription to be entrained at a common pace. Intervention theory and action research, viewed through the mangle of practice, ensured that the work was decentred, without no primary role of expert or best method, allowing a dynamic interaction between all of the actors in which worldviews were freely altered.

Many of the improvements came about by accident or by incidental learning that was taken up and used, hence the bridgehead of changing forecast understanding and use came about as a group act, like a boat on the water moving with the prevailing current. This enabled the forecast use to be improved in a natural way which had internal commitment: they became the stakeholders' interventions so that CJP could step away whilst improvement was maintained. The valid information was developed together so it was trusted and double loop learning was achieved (Argyris, 1977).

Bridgeheads/emergent actions	Resistance	Accommodation	Transcription/filling	Prior research addressed
Forecast laid bare, ready to improve, forecast audit, demand profiling.	Most do not believe demand is smooth with a few spikes. System not fully understood.	New software helps to create views for managing the exceptions enabled by analytics and good data management. System understanding improves by taking different views.	Staff help to source the data and create the views for managing by exception, eventually becoming the creators. Awareness raised about judgemental adjustments and intermittency in sales.	*'putting it on the table'* (Deschamps et al., 2005) Forecast process improvement in practice. (Moon et al., 2003) Forecast audit. (Fildes et al., 2009) Biasing due to judgmental adjustments. (Syntetos & Boylan, 2001) Biased intermittent forecasts.
A move toward a questioning data driven culture improves forecast quality in use.	Large changes and new ideas are difficult to learn and accommodate.	Being reflexive and ensuring analytics have a behavioural fit. Small iterations to improve *'solve a little pain'* each time changing the path dependence of the group and forecast improvement.	Participative actions use research knowledge. Group derived knowledge and tools are put to use. Contextualised visualisations enable transcription of models (e.g. MAPA, CDF's, lead time histograms)	(Luoma, 2015) Behavioural fit. (Mello & Stahl, 2011) Culture change and forecasting. (Hämäläinen & Lahtinen, 2016) Path dependence and change.
The above improvements require creation of new views of available data.	Data stored in three different systems and matching difficult across levels.	New software sourced. Data blended and loaded into new databases. Master data files and new data procedures created.	Staff take up and use new software, asking for specific changes. New knowledge emerges from new data views. Creates improvements and prompts further changes.	(Fildes & Hastings, 1994; Fildes & Petropoulos, 2015) Data systems as barriers to improvement. (Li, Thomas, & Osei-Bryson, 2016) Knowledge emerging from analytics development.
Many small changes to improve demand forecast use when planning create large systemic changes and savings.	Large changes and new ideas are difficult to learn and accommodate.	Agile participative design. Changes must be small and structured to fit working practice, entrained at the right pace for the user. This way they build on each other.	Better demand management leads to inventory reduction and reduced MPS nervousness.	(Ancona & Chong, 1996) Entrainment of work. (Orlikowski, 2000) Structuring of technology and work. (Syntetos, Nikolopoulos, & Boylan, 2010) Large improvements in inventory from small changes at forecast.
Forecast information sharing deficit– move to measure BullWhip Effect.	Language barriers across functions. Necessary data is not recorded.	Language barriers are opened up. Data cannot be accommodated. Different methods of variation mapping and understanding are employed.	Communication improves. BWE is better understood aggregation effects are identified and managed by planners.	(Croson & Donohue, 2006; Lee, Padmanabhan, & Whang, 1997b; Wang et al., 2014) Bullwhip effect and information sharing. (Oliva & Watson, 2011) cross functional alignment can be more important than information sharing.
Information sharing and communication of forecast internally is improved.	Did not want to have less information for fear of slow reaction.	Models show how variation reduces if demand is temporally aggregated. Staff admit gaming system to favour some items and learn how to help other areas. Also gain knowledge re; demand variation and forecast accuracy.	Forecast use is limited to demand planners. They manage by exception and plan is frozen at 14 weeks. Understanding about forecast limitations and sales patterns is improved.	We have found no other research noting a negative effect due to too much information sharing. Poor communication of forecast information and risk has been observed in research (Moon et al., 2003; Oliva & Watson, 2009, 2011) .

Table 1. Describes the evolving process of the Mangle of Practice (Pickering, 1995)

To understand how the action research requirement of reflexivity affected the research we can look at the intervention which did not occur; the attempt to map and control the bullwhip. SM steered the research away from this goal although CJP was keen to pursue it; SM had an agenda to implement continuous flow in production and felt that smoothing via controlling the bullwhip would not help this, a case of instrumentalisation which is common in a reflexive environment (Westling et al., 2014). CJP was interested in mapping the effect of bullwhipping and the possibility of controlling the WIP and inventory inputs using gain controllers, her standpoint as an analytics practitioner, known as '*the practitioner's dilemma*' (Corbett, Willem, & Wassenhove, 1995). Had the data been available and the research not as reflexive (to SM's concerns) the bridgehead for the supply chain forecast part of the intervention could have focussed instead on an analysis, mapping and controlling of bullwhip. This intervention would have reduced the opportunity for participation since it was technically more complex and required more from the transcription of CJP's expertise and input from the data systems. Using bullwhip controllers would also require much less collaboration in development, therefore organisational learning at an accessible level, and double loop learning, would have been less likely to occur.

8. Conclusion

In this research we have shown that if a researcher is actively engaged in the organisation under scrutiny the practitioners are receptive to new ideas as small positive iterations lead to larger changes. We saw that forecast information can be used in unexpected ways which can cause disruption and that behaviour errs on the side of caution when it comes to being reactive. The descriptive power of the mangle provided recoverable information which can be compared against other research findings and has proven to be a useful lens for studying sociotechnical systems through action research.

If action research were used to develop and embed a new forecast function then the associated method of Design Science could be used (Holmström et al., 2009). Design Science's intervention is artefact development and it has been used successfully in Information Systems and Decision Sciences research (Hevner et al., 2004; Li et al., 2016). Design Science provides a possible way to study organisations that need new forecast support systems, or adendums to their existing systems, such that it satisfies both academic and practitioner requirements whilst opening up the socio-technical aspects of forecasting systems. When studying and attempting to improve interraction, functional alignment and forecast perception, action research and grounded theory, used to aid effective collaboration, helps us to satisfy both the practitioner's requirements and to further academic understanding.

This study is limited due to being a single case study, however it concurs and corroborates with the the results of the action research project described by Caniato et al. (2011). We also found that collaboration enables an effective design process that opens up understanding and increases alignment. The findings also agree with Propostion IV of Oliva & Watson (2011);

> *'The pursuit of alignment in organizational planning can be more important than achieving particular levels of informational or procedural quality'*

In this case study, when the planning and testing teams had perfect knowledge of the inventory position, they were over reacting to the information due to a lack of knowledge regarding the effects that this could have. It was only after a period of cross functional engagement and knowledge creation through the action research that they were able to achieve a consensus regarding process that improved many aspects of the system. A virtuous cylce was set up, where the positive impact of one intervention would mean that the next was taken up more readily *'solving a little pain'* as SM put it, this also concurs with Oliva & Watson (2011).

More exercises of this kind, particularly if written using the mangle, would be valuable in providing a body of research regarding methods for integration and improvement of forecasting. We have already confirmed some existing research surrounding interventions, modelling and forecast improvement (see Table 1). In particular we saw that the procedure surrounding forecast use and integration is of primary importance for improving use in practice (Caniato et al., 2011; Oliva & Watson, 2009, 2011). When we enable a cross functional collaboration between all parties using a forecast the structure of forecasting problems are laid bare; and we are able to go beyond accuracy measures and look at other supply chain performance metrics and efficiencies. When improvement is performed in this way knowledge is created and assimilated allowing for a re-structuring of ideas and processes (Kellogg, Orlikowski, & Yates, 2006; Orlikowski, 2000) and an entrainment across functional boundaries (Ancona & Chong, 1996; Ancona & Waller, 2007).

Many of the insights gained here can be built upon, the limitations of using visual analytics would be one avenue for further research as would the perceived need for high velocity information and the effects of unexpected use of forecast information: also perceptions surrounding aggregation effects in the supply chain, and how these differ across functions. When presenting this work one reviewer noted that it is a time consuming process (this study took 3 years). We hope that by extracting the 'what worked' elements of the action research we can enable others to use these methods to engage effectively in shorter time frames;

- All processes using the forecast need to be documented and laid bare and the creation of a cross functional group to do this is desirable (Oliva & Watson, 2009, 2011).

- A forecast audit with the inclusion of forecast users creates new knowledge and enables good process design (Caniato et al., 2011; Moon et al., 2003).
- Qualitative techniques such as reflexive action research and grounded theory have the ability to illuminate forecast research relevance which helps to contextualise solutions for the practitioner.
- Culture and change management are integral to good forecast process management (Caniato et al., 2011; Moon, 2006; Oliva & Watson, 2009)

Visualised analytics and forecasting algorithms have shown their potential as a tool for expert forecasters and analysts to engage with practitioners effectively. Relevant contextualised pictures that describe mathematical models can penetrate opaque processes if they achieve a behavioural fit (Luoma, 2015). The relevant context can be found through interpretive methods like action research that encourage a free expression of views. Large scale changes to improve forecasting awareness and use in the supply chain can succeed through small scale innovations and commitment and we have shown that this can be enabled by iterative, collaborative development that provides a catalyst for cultures to change from within.

Acknowledgements and Funding

To be added after the final acceptance of this article – this paragraph is provided in the TITLE PAGE

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