Understanding resilience, productivity and quality in production teams

Understanding Resilience, Productivity and Quality in Production Teams: Data from a Manufacturing Simulation

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Abstract

Interest in resilience is on the rise. In Operations Management, much attention has focused on supply chain resilience, to the exclusion of in-company resilience. Implicit in this is an assumption that resilience mainly concerns resistance to, and recovery from, major disruptions. We challenge this assumption in two ways. First, we argue that resilience is relevant to operations within as well as between organizations. Second, we use a simulation of a manufacturing process to demonstrate empirically that resilience is associated with other aspects of manufacturing performance such as productivity, quality and agility.

Keywords: Resilience; teams; productivity; quality

Many organizations struggle to perform in the face of challenging, unusual conditions. Many commentators argue that the world is more replete with challenging conditions than ever before and an acronym has emerged to describe this – "VUCA" - volatility, uncertainty, complexity and ambiguity (Bennett and Lemoine, 2014). In the Operations Management (OM) literature it is interesting to see increasing numbers of papers on resilience, a development also mirrored in the mainstream management community (Van Der Vegt et al., 2015). Resilience, typically, covers both the ability to anticipate difficult conditions and the ability to absorb, respond to and bounce back from trauma (Van Der Vegt et al., 2015).

In Operations Management much of the interest in resilience focuses on supply chains, unsurprisingly given global supply chains and the risk of disruption to these

(Olcott and Oliver, 2014, Ambulkar et al., 2015, Nishiguchi and Beaudet, 1998). Work on the resilience of individual enterprises is not so common in OM, and studies of resilience at the level of production teams is even less so, although such teams are often the building blocks of larger organisations and systems. This is a curious omission given the significance of production teams to the performance of many manufacturing systems (Womack et al., 1990, MacDuffie, 1995, Delbridge et al., 2000).

Interestingly, some of the most influential work on resilient teams and organizations has not come from mainstream Operations Management, but from studies of "high reliability organizations" (HROs), often based on a sensemaking perspective. HROs have distinct features and routines that enable them to operate safely and consistently, despite complexity, tight coupling and high interdependencies (Weick and Sutcliffe, 2007). Complex, demanding environments in which safety and reliability are highly valued, such as aircraft carriers (Weick and Roberts, 1993), electricity grids (Roe and Schulman, 2008) and commercial aviation, amongst others, have all been used as case studies of HROs. We observe that with increasing interest in resilience and how it is created and sustained, the principles of HROs carry important implications for less safety-critical organizations. HROs may be "templates of adaptive organizational forms for complex environments" (Barton and Sutcliffe, 2009) and models for "dynamic and adaptive organizing which ultimately results in better performance" (Barton et al., 2015). However, despite these assertions, few attempts have been made to explore how HRO principles may apply in less extreme contexts, or to empirically investigate the relationship between certain HRO principles and other measures of performance. The studies that have perhaps closest to bridging the gap between HROs and OM have tended to focus on how manufacturing operations recover from major traumas (Olcott and Oliver, 2014, Nishiguchi and Beaudet, 1998, Sheffi, 2007, Sheffi and Rice Jr, 2005) or on the organizational conditions for effective problem-solving (MacDuffie, 1997).

In this paper, we seek to address this situation by using a simulation of a manufacturing operation to empirically test the relationship between resilience and manufacturing performance. Our key research question is "In a simulated manufacturing environment, is there a relationship between resilience and other measures of manufacturing performance, such as productivity and quality?"

Methods

Our study is based on a business simulation in which 345 student participants, working in teams of 7-9 members, were required to select orders for greetings cards from a market place and physically produce the cards to exacting quality standards under competitive, time constrained conditions. The exercise generates objective performance data in terms of profit/loss, physical productivity (cards produced per head) and quality (percentage of orders rejected due to defects).

The participants in our study were postgraduate students pursuing one-year MBA and MSc programmes at the University of Edinburgh Business School during 2015-16 and 2016-17. The simulations in which they took part formed part of their course in Organizational Behaviour. The educational purpose of the simulation was to provide experiential learning in the form of a hands-on exercise in strategy and organization on which students could reflect. Students' grades were not linked to performance in the exercise, although they were required to produce a reflective assignment in the weeks after the exercise, which was graded.

The participants were randomly allocated into 43 teams of 7-9 members, most teams having eight members. MBA students comprised 25.2% of participants, the remainder being MSc students. Overall, 63.2% of participants were female. Participants were of quite diverse nationalities, with a total of 66 different nationalities represented, the highest proportions being from China (25%), followed by Germany (11%), the UK (10%) and the US (7%). The exercise was run four times, comprising two MBA games, of six teams each and two MSc games of 15 and 16 teams respectively.

The Game comprises two main phases. The first is a preparation phase which lasts 4-5 weeks. Participants are randomly allocated to teams at the beginning of this phase and the members of each team must work together to decide issues of strategy, organization and operations and prepare themselves for an intense “trading period”. The trading period is the second phase of the Game and lasts two and one quarter hours (135 minutes). This is a high-energy, competitive period during which teams in each game compete directly to obtain, produce and deliver orders of cards. The trading period tests the resilience of the production teams in that their strategies and systems developed during the previous four weeks must operate under dynamic, uncertain and competitive conditions. One of the real advantages of the Game in research terms is that it yields measurable, objective results on the performance of each team.

The Game creates a number of difficult-to-resolve trade-offs for the teams (Skinner, 1974, Da Silveira and Slack, 2001), the principle ones being between speed of production, quality of cards, the pressure experienced by team members, flexibility (the ability to deal with uncertainty and unexpected conditions) and profitability. The orders with the highest margins are large ones that must be produced to short deadlines, and which therefore require high production speed. However, fast production can compromise quality by increasing the risk of smudging and mistakes in stencilling and verse writing, which violate the quality criteria. There are also financial constraints. Teams must buy equipment and materials from the controllers, and these must be covered by a loan on which interest is paid. Equipment and materials heavily depreciate in value during the Game (even if they are not used) so teams must plan and manage their finances carefully and keep their operations in as lean as possible. Too much investment and they will not be able to recoup their costs during the trading period. Too little investment will leave teams short of the productive capacity they need for more demanding orders and also rob them of slack and flexibility to deal with unexpected conditions.

At the beginning of the exercise all participants receive a comprehensive briefing document of about 4,000 words which contains all the essential information about the Game. The briefing document requires careful analysis, interpretation and interrogation by the teams as it is the main source of information from which strategy and organization are developed. There is some purposeful ambiguity and incompleteness in the brief, but teams can seek clarification from the Game’s controllers.

A few days before the trading period each team submits a strategic plan to the controllers, outlining their basic approach to the Game, including their strategy, assessment of risks and financial and production forecasts. The plan also includes a pre-order of equipment and materials for the trading period and a request for loan finance to cover the cost of these and to provide working capital. Teams pay interest on this loan (at 10%). Emergency loans can be obtained during the trading period but at a much higher rate of interest. The pre-order of equipment and materials supplements a standard basic kit of materials that is issued to all teams on the day of the Game, the purpose of which is to protect teams from catastrophic misjudgements about their equipment and material requirements before the Game even begins. Each team has a 30-minute “strategic review meeting” with two controllers during which they are probed about their plans and forecasts and the assumptions that underpin them.

Apart from the briefing document, teams are not provided with any material and equipment during the preparation phase, although they can borrow equipment and materials for short, fixed periods in order to practice. Some teams do so multiple times; others not at all. Teams are allowed to make jigs and templates for use in the trading period, which must be approved by the controllers before they can be used.

All teams are issued with their standard basic kit of equipment and materials first thing in the morning of the trading period. Any additional materials that teams have pre-ordered are available when trading commences. Only materials and equipment purchased from, or approved by, the controllers can be used in production.

For each Game, trading takes place with all teams located in a single large room. Each team has its own large table; locations are allocated to teams by open auction a few days ahead of the trading period in which teams can bid for their preferred location. There is a dedicated ‘control area’ in the trading room where the controllers are located from where they:

1. Issue orders for batches of cards to the teams from the order board
2. Inspect the completed batches of cards that the teams produce and pay teams for those that are completed on time and to specification
3. Take orders for extra raw materials and equipment from the teams and prepare and issue these. These orders carry a 10 minute lead time.

There are several controllers for each game, in the ratio of one controller for approximately every 12 participants.

Around 15 orders are displayed on the order board at any one time. Each order is printed on a single sheet of paper known as a ‘Sales Order and Delivery Notice’ (SODN). Each SODN specifies an occasion (Christmas, Birthday, etc, 36 different occasions in total); the number of lines of verse (2, 4 or 6); the number of cards in the batch (4, 8 or 12) the colour of the cards (6 different colours); the size of cards (A5, A6 and A7); and the delivery lead time (open, 30, 25, 20 or 15 minutes). There are thus 29,160 potential variants of order. In practice only around 40 of these variants are actually used, although the teams do not know this and therefore face considerable uncertainty and potential market variety as they enter the trading period. Limited data on market conditions are provided in the initial briefing document, but sufficient to enable teams to develop a good understanding of order pricing and other parameters. The price that a team will receive for an order if it is delivered on time and to specification also appears on the SODN.

The order board sits behind a low barrier so that teams can see the orders but not touch them. To obtain an order a team member must ask a controller, who takes the SODN, notes the time at which the order is due, and signs the order out to that team. As orders are taken, the order board is replenished from a bank of orders, so that teams always have a choice of orders to take. The orders in the bank are predetermined; thus if several teams all target the same type of order (eg colour, lead time or occasion) the market can become starved of that type of order. There is thus a ‘theoretical’ market, determined by the order bank and a ‘realized’ market that actually confronts the teams at the order board, the latter being determined by the aggregate effect of the independent order-taking strategies of the teams. Games thus have emergent dynamics depending on the combination of strategies pursued by teams on the day. This is a major source of uncertainty, and can force teams to radically adjust their strategies during the trading period. This ability to read their environment, synthesize the information coming in and rapidly construct appropriate, coordinated responses has been noted as foundational to the resilience of HROs (Weick and Sutcliffe, 2007) and rapid recovery from major events (Nishiguchi and Beaudet, 1998, Olcott and Oliver, 2014).

Teams have access to the trading room about 30 minutes before trading commences and use this time to arrange their equipment and materials and make final preparations for trading. There is usually a strong sense of excitement and anticipation in the room which is further encouraged by a background slide-show of images of "extreme" teamwork (e.g. Americas Cup crews, Formula 1 pit stop teams, aircraft carrier flight decks during launch and recovery) accompanied by loud backing music to enhance the sense of excitement and anticipation.

The start of trading is signalled by the ringing of a loud bell. This triggers a frenzy of activity around the order board as the order-getters from each team jostle for position and shout to the controllers in order to obtain the orders that they want – the effect is similar to crowds of people trying to obtain drinks in a noisy bar. Teams also collect any materials and equipment that they pre-ordered and production commences. Teams can take on as many orders as they wish.

As teams complete their orders they deliver these to an inspection and quality control area, where controllers inspect the cards. The controllers check various parameters such as placement of margins, text alignment, lines of verse, freedom from smudges, pencil marks and completeness of the order and other parameters. Teams are paid on the spot in cash (using counterfeit money) for orders that meet the specifications. To ensure consistency of quality standards two controllers must concur on a rejection verdict. Teams receive no payment for rejected orders. When an order is rejected a whistle is blown. In a typical game, around 20% of all orders are rejected, so whistles sound frequently in the trading room.

To perform well during the trading period, teams must quickly make decisions that require several parameters to be assessed and evaluated. This is not always easy, as the information needed to make the decision may be distributed between multiple team members. For example, a decision about which order to pick requires the order-taker to consider:

a) The order selection criteria that the team had agreed in advance of the trading period
b) The availability of materials (bearing in mind the 10-minute lead time on raw material orders)
c) The availability and capability of the team's production line/s
d) The willingness of the production line to accept the order (sales-production conflicts are commonplace during the trading period).

Hesitation in picking an attractive, profitable order is likely to result in the loss of that order to another team. Careless or ill-timed selection means that the production members of the team may be busy manufacturing orders that are already in-process or the necessary raw materials may not be in stock.

The trading room is thus a busy, noisy environment, with team members running between the order board, inspection and quality control and the raw materials station. Conversations between order-takers and their production colleagues are often shouted across the trading room. Teams can trade materials with each other and many do. Interdependencies are high and coordination and control are major challenges, especially for teams whose base is located some distance from the order board across a large, noisy, crowded room. There is plentiful scope for breakdowns in communication and for teams to "lose the bubble" (Rochlin, 1997) in the fast-moving environment.

Tension between order-takers and production personnel is commonplace because the highest value orders, which are generally most attractive to the order-takers are also those that place the most stress on production. Good control and visibility of inventories of paper is needed, otherwise orders may be taken which cannot be fulfilled in time due to material shortages. The problem of inventory control is exacerbated by wastage due to during errors in stencilling or verse writing. Time pressure is further intensified because late orders are not accepted and also attract a penalty charge of 20% of the value of the order, a measure that prevents teams taking orders that they have no intention of fulfilling as part of a 'spoiling' strategy against other teams. Competitive pressures mean that most teams become very psychologically invested in performing well.

At the end of the trading period, teams return all their equipment, unused paper and cash and a final financial position is calculated from this. Given that all teams started with exactly the same information and resources five weeks before the trading period, differences on these measures can largely be attributed to teams' choices and processes during the five weeks of preparation and to their ability to convert plans into actions during the trading period.

The Game generates objective performance data about the performance of each team, in terms of financial performance (profit or loss), physical productivity (cards per team, cards per head), quality (% of orders that fail to meet the quality standards) and dependability (% of orders not completed and delivered by the delivery deadline).

Resilience was measured using a lightly adapted version of a nine-item scale developed to assess conformity to the HRO organizational model (Vogus and Sutcliffe, 2007, Weick and Sutcliffe, 2007). The scale is reproduced in Figure 1. The adaptions converted the original three-point scale to a five-point scale and involved some minor changes to wording to ensure that the scale was appropriate for team-level application. This scale captures "specific behaviours [seen] in more highly reliable organizations" and measures capabilities "for error detection and correction" (Weick and Sutcliffe, 2007).

1. We had a good "map" of each person's talents and skills
2. We talked about mistakes and ways to learn from them
3. We discussed our unique skills with each other so that we knew who has relevant specialized skills and knowledge
4. We discussed alternatives as to how to go about our normal work activities
5. When discussing emerging problems with co-workers, we usually discussed what to look out for
6. When attempting to resolve a problem, we took advantage of the unique skills of our colleagues
7. We spent time identifying activities we did not want to go wrong
8. When errors happened, we discussed how we could have prevented them
9. When a crisis occurred, we rapidly pooled our collective expertise to attempt to resolve it

Figure 1: Measurement of Resilience

Individual participants completed this scale before and immediately after the production period. Individual scores were aggregated to produce a resilience score for each team. As a check that the Game was indeed replicating stressful, challenging To check this, participants were asked to rate how often they experienced certain feelings, both positive and negative, during the trading period, using a five point scale, ranging from never to always. This scale is a shortened version of Warr's "affective well-being" scale (Warr, 1990) which asked participants how often they experienced a variety of psychological states (e.g. tense, uneasy, worried) during the trading period. Participants were also asked whether their team experienced a crisis or crises during the game, using a simple YES-NO response code.

Findings

We begin by examining the conditions encountered by participants during the trading period and assess whether the Game represents a challenging, demanding environment and therefore serves as a test of resilience. These results are presented in Table 1.

Percentage of participants who reported:	
Feeling "tense" (always, often or sometimes)	78.4%
Feeling "uneasy" (always, often or sometimes)	54.1%
Feeling "worried" (always, often or sometimes)	55.0%
Feeling "miserable" (always, often or sometimes)	14.9%
That there were times they felt their team "lost it" during the game	17.4%
That their team experienced a crisis (or crises) during the game	53.6%
Percentage of teams that made a profit	18.6%
Percentage of teams that had at least one rejected order	86.0%

Table 1: Psychological Conditions during the Trading Period

Table 1 indicates that the trading period was experienced as demanding by the majority of teams and participants. We note that nearly 80% of participants reported feeling "tense" at least sometimes during the trading period (this percentage excludes the participants who stated that they only rarely felt tense). More than half of the participants reported that they felt "uneasy" and "worried" during the game, at least 'sometimes'. Moreover, more than half of the participants perceived that their team experienced one or more crises during the game. The vast majority (86%) of teams had at least one order rejected. It should also be noted that most teams (around 80%) made a loss, indicating how difficult it is for teams to enact all the tasks necessary for profitable trading. Several teams returned disastrous financial results.

Table 2 shows the summary performance statistics of all 43 teams. These highlight the substantial differences between teams in terms of their objective performance. The scale of the differentials between the best and the worst teams are quite startling – nearly 14:1 on cards per head and 36:1 on value of sales per team. Reject rates, a measure of a team's ability to interpret the specifications and then reproduce them accurately and consistently varied from no rejects at all to 67% - two thirds of their production rejected by the inspectors due to quality issues.

	Mean	**Minimum**	**Maximum**
Number of good cards produced per team	78.8	8	148
Number of good cards produced per person	9.8	1.2	16.6
Number of successful orders per team	10.3	2	20
Orders rejected as percentage of orders delivered	20.7%	0%	66.7%
Orders unfulfilled as percentage of orders taken	6.7%	0%	44.4%
Value of sales per team	£4228	£270	£9850
Profit/loss	-£1280	-£4545	£2247

Table 2: Summary Performance Data

As stated in the introduction, a key purpose of this study is to empirically test for a relationship between resilience and other measures of manufacturing performance, such as productivity and quality. Theoretically there seem to be strong arguments as to why such relationship should exist, but are they found in practice? Table 3 shows the correlations between team scores on the resilience scale and the objective measures of team performance.

Financial performance - profit/loss	0.61 ($p<.01$)
Productivity - cards per head	0.54 ($p<.01$)
Quality - defect rate	-0.65 ($p <.01$)
Value of sales per head	0.58 ($p <.01$)

Table 3: Correlations between Resilience and Performance (43 Teams)

The correlations in Table 3 are consistent in their strength and show moderately strong, positive relationships between resilience and objective measures of financial performance, physical and financial productivity. Resilience is strongly and negatively associated with quality problems. All correlations are significant at $p<.01$. Resilience also correlates negatively with strength of perception of crisis within a team (-0.39, $p<.05$) and with propensity to take demanding, high-value orders (+0.50, $p<.01$).

Thus, the findings support the view that there is a symbiotic relationship between resilience and other dimensions of manufacturing performance at the level of the production team. In the section that follows we discuss the mechanisms and implications of this.

Discussion and Conclusions

As noted in the introduction, in the Operations Management literature, as in other literatures, resilience is often seen as an issue relevant to major disruptions, particularly supply chain disruptions. In many ways, this is not surprising; as global production networks have developed, concerns about disruption due to distant events whose nature and probability may be difficult to assess have risen accordingly. Acronyms like 'VUCA' have partly emerged as a shorthand way of expressing these concerns.

However, amid concerns about supply chain disruption and resilience, the significance of resilience to internal operations seems to have been overlooked. This seems curious, given that supply chains are made up of multiple organizations, engaged in highly interdependent activities. The resilience of specific units and processes is therefore foundational to the resilience of the end-to-end system.

In preparing this paper we conducted a search of back issues of the *International Journal of Production and Operations Managemen*t (IJOPM) covering the period 2010-2017 and were struck a) the predominance of supply-chain orientated papers and b) by the paucity of material on resiliences. Papers concerned with the resilience of individual organizations, let alone units or processes within them, were conspicuous by their absence. In part this may be because resilience is inherently difficult to research. Resilience is based on a set of capabilities that can be subtle and hard to see. Moreover, the presence, absence and efficacy of these capabilities can be hard to assess until they are put to the test via a "brutal audit" in Weick and Sutcliffe's terms (Weick and Sutcliffe, 2007). By their very nature, such audits tend to occur unexpectedly and require rapid response; most organizations do not welcome researchers under such circumstances, and even after the event there may be post-hoc reconstruction of events to deflect blame and responsibility. This may be one reason why much of the "in-close" work on resilience has been done either on HROs, where the emphasis is on understanding how problems, errors and disruption are avoided in the first place, or on major disasters, where documented evidence from public enquiries exists (Weick, 2010).

Considerations such as these took us down the route of the simulation described in this paper. As we have seen, the simulation yielded measurable, comparable performance across teams performing directly comparable work. We were able to take independent measures of resilience, and other key conditions (tension, stress, sense of crisis) and empirically test for relationships between resilience and performance. As the data show, we find strong, consistent evidence of a relationship between scores on the resilience scale and independent measures of manufacturing performance.

Our interpretation of this lies in concepts and capabilities that, strangely, are only occasionally found in the mainstream Operations Management literature but are prevalent in the literature on high reliability organizations. These include: the ability to interrogate the environment and build up valid, sophisticated representations of this; the ability to constantly update these as circumstances change; a capacity to pool information, even across organizational and other boundaries; and to respond quickly and appropriately. Examples of these capabilities at work do exist in the OM and related literature – they are just not very common (Olcott and Oliver, 2014, MacDuffie and Helper, 1997, Nishiguchi and Beaudet, 1998, Sheffi, 2007). However, our findings suggest that these capabilities also have significant benefits in day-to-day operations, not just when it comes to disaster recovery.

Of course, using a simulation such as the Production Game has limitations. Our teams had a high degree of discretion over the design and organization of their manufacturing systems and choices made during the preparation phase carried consequences during the trading period that, strictly speaking, were not directly related to a team's ability to tolerate difficult conditions. In many manufacturing environments, process design and process operation may be rather more separate than was the case here, and future research designs could try to separate out these two aspects. However, we observed that because of the uncertain dynamics of the Game, almost all teams had to make real-time modifications to their original system designs. The ability to do this seemed to be one of the hallmarks of the more successful teams. Indeed, some teams appeared to be so captured by their original designs and plans that they persevered with these, even in the face of overwhelming evidence that they needed to stop and re-configure.

A second potential limitation is the use of postgraduate students, with limited work experience, to simulate responses to challenging, stressful conditions. Would more experienced practitioners respond in the same ways? We do not have a definitive answer to this, but we do have some indications. Subsequent to the six games described in this paper, we have run one more game, comprising four teams, with participants who were all in employment and on average about 10 years older than the full-time MBA and MSc students who made up the original 43 teams. On average, these four teams appeared to adopt significantly more conservative ordering strategies, conducted more fulsome (but somewhat inhibiting) upfront risk assessments and were less prone to improvise during the game. There were no disasters, but no star teams either.

Thus, while there are undoubtedly limitations from using a simulation such as this, we suggest that these limitations are more than offset by the benefits of transparency and visibility of resilience processes and by the ability to relate these, systematically and empirically, to objective outcomes. The challenge for future research into resilience is to find real-world settings in which these conditions also apply.

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