Routledge
Taylor & Francis Group

Construction Management and Economics

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rcme20

Improving construction management with decentralised production planning and control: exploring the production crew and manager perspectives through a multi-method approach

Joonas Lehtovaara, Olli Seppänen & Antti Peltokorpi

To cite this article: Joonas Lehtovaara, Olli Seppänen & Antti Peltokorpi (2022) Improving construction management with decentralised production planning and control: exploring the production crew and manager perspectives through a multi-method approach, Construction Management and Economics, 40:4, 254-277, DOI: 10.1080/01446193.2022.2039399

To link to this article: https://doi.org/10.1080/01446193.2022.2039399

Published online: 21 Feb 2022.

CONSTRUCTION MANAGEMENT AND ECONOMICS
2022, VOL. 40, NO. 4, 254–277
https://doi.org/10.1080/01446193.2022.2039399

Routledge
Taylor & Francis Group

Improving construction management with decentralised production planning and control: exploring the production crew and manager perspectives through a multi-method approach

Joonas Lehtovaara, Olli Seppänen and Antti Peltokorpi

Department of Civil Engineering, Aalto University, Finland

ABSTRACT

Decentralised, autonomous planning and control is a potential avenue of improvement in several fields, including construction. However, research on this topic, particularly involving the production crew viewpoint, remains scarce within the construction production management domain. This study explores the effects of decentralisation (and in contrast, effects of centralisation) for construction production planning and control (PP&C) from the combined perspectives of production crews and managers, and utilises these viewpoints to suggest improvements for PP&C practices. The study answers the following research questions: *How do decentralisation/centralisation affect construction PP&C practices when considering both the production crew and manager perspectives?* and *Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?* To achieve holistic assessment, the research is conducted as a multi-method comparative case study using survey-based social network analysis (SNA) and semi-structured interviews. The results show that decentralised PP&C offers several benefits—such as improved transparency, conflict resolution, commitment, and lower stress—while allowing a proactive building of resilience, trust, ownership and autonomy for crews. In its current applied form, however, the approach does not fully reach the worker level. Regardless of the approach that is used, production crews perceive PP&C as decentralised, while managers perceive PP&C as having centralised structures. This gap between perceptions forms barriers for effective PP&C that must be properly addressed. Eight improvement suggestions are constructed to improve PP&C, that generally emphasise more deliberate decentralisation but that also indicate the necessity of partial central planning and control.

ARTICLE HISTORY
Received 9 December 2020
Accepted 3 February 2022

KEYWORDS
Construction production management; decentralisation; production planning and control; case study; social network analysis

Introduction

Construction projects form complex, networked and dynamic entities (Baccarini 1996, Bertelsen 2003) where success depends on effective production planning and control (henceforth PP&C) (Koskela 2000). PP&C is an essential part of production management that forms a process of deciding what and when to produce (and with which capacity and resources) and ensuring that the production is executed and steered accordingly (Vollmann 1997). Traditionally, construction PP&C has relied on hierarchical governance, orchestrated by a master planner, but scholars have long questioned these centrally led practices for their effectiveness in managing increasingly complex production systems (Johnston and Brennan 1996, Koskela *et al.* 2019). While centralised PP&C does have its benefits, construction production could benefit from adopting more decentralised[1] management practices (Bertelsen and Koskela 2005).

Decentralised, autonomous decision-making has become a key element in effective project, organisation and production management (Laloux 2014). The benefits, such as increased productivity, improved worker well-being and enhanced agility to respond to changes, have been demonstrated in several fields, including information technology (Salovaara and Bathurst 2018), the military (Bertelsen and Koskela 2005, Marquet 2012, McChrystal *et al.* 2015) and automobile manufacturing (Liker 2005). In construction, the decentralisation of PP&C has previously been studied and implemented especially in the domain of lean construction through methods such as the Last Planner® System, or LPS (Ballard 2000), which has

CONTACT Joonas Lehtovaara joonas.lehtovaara@aalto.fi Department of Civil Engineering, Aalto University, Aalto, Finland

shown promising results in increasing production performance (Castillo *et al.* 2018). Studies of construction industry culture indicate that employing decentralisation more widely would be a welcome change amongst industry professionals. Teräväinen *et al.* (2018) state that people working in construction would prefer to operate in organisations and projects that embrace creativity, autonomy and a rule-breaking attitude rather than adhering to hierarchical structures.

Despite these promising ideas on how to improve construction management through more decentralised PP&C, the viewpoints of production crews (which primarily consist of trade crew leaders and workers) are rarely investigated. Several authors, such as Loosemore (2014), Diekman *et al.* (2004) and Hinze and Tracey (1994), have criticised the fact that even though production crews are vital to the construction supply chain and are essential parts of successful PP&C, the presence of their viewpoints in construction production management studies is almost non-existent; instead, studies often focus on the managerial viewpoint of general contractors (GCs) or clients. Loosemore (2014) rightly argues that a far more balanced view within construction management research is needed.

Motivated by this research gap, this study aims to explore the effects of decentralisation (and in contrast, effects of centralisation) on construction PP&C by taking into account the perspectives of both production crews and managers. Based on insights gained from these perspectives, suggestions are presented on how construction PP&C practices could be improved overall. The aim is pursued through answering the following research questions:

- RQ1: How do decentralisation/centralisation affect construction PP&C practices when considering both the production crew and manager perspectives?
- RQ2: Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?

The remainder of this paper consists of five sections. First, the theoretical background section introduces literature related to the philosophical and theoretical underpinnings of centralised and decentralised management, current practices in construction PP&C, and the perceived benefits, disadvantages and drivers of decentralised PP&C on a general level. Next, to further investigate the production crew and manager perspectives of decentralised/centralised PP&C, the methodology and results sections cover a comparative case study of two Finnish construction projects that utilised social network analysis (SNA) and semi-structured interviews. The discussion section reflects the results in light of the literature before the paper concludes with study contributions, limitations and future research suggestions. To maintain focus, the study is limited to planning and control of the production phase of construction projects, the units of analysis being construction crews, managerial teams and individuals in the production context.

Theoretical background

Centralised and decentralised management: philosophical and theoretical underpinnings

Since the mid-twentieth century, mainstream engineering and construction management practices have been heavily influenced by a Platonian (i.e. introduced by the Greek philosopher Plato, 427–347 BCE) view of the world (Koskela *et al.* 2019). In the Platonian view, knowledge can be deductively acquired from abstract ideas or universal truths and then put into action through a plan; events after the implementation of the plan and observations about the execution are of lesser interest. This view forms the centralised approach to management and has laid the foundation for the current dominant ways of PP&C that Johnston and Brennan (1996) articulate as the theory of "management-as-planning" (MaP). Akin to the Taylorist approach, where management is primarily seen as autocratic action (Taylor 1947), MaP starts from an assumption that production consists of two independent parts: the plan is first centrally formed by an all-knowing manager and then precisely executed by production crews. However, scholars have increasingly criticised this approach over the past few decades; Johnston and Brennan (1996), for example, argue that this autocratic perception of management, in which management and action are separated, is a widely held but naive assumption that does not provide a realistic conception of the world or of production. Bertelsen (2003) and Pollack (2007) argue that forming an accurate plan that would separately guide actions effectively is impractical due to the complex, networked and dynamic nature of projects and production systems.

An Aristotelian view of the world, introduced by Plato's student Aristotle (384–322 BCE), provides an alternative approach. In the Aristotelian view, in addition to deduction, knowledge is acquired inductively, drawn from the observations and perception of those participating in the action (Koskela *et al.* 2019). This view forms the decentralised approach to

management, in which the viewpoints of actors and their responses to the present situation are essential. Johnston and Brennan (1996) articulate this view as "management-as-organizing" (MaO), in which the manager takes the role of coordinator and enabler, giving production crews and actors within crews authority in the PP&C process. In this view, these actors are not seen as homogenous subordinates but instead as motivated individuals who are capable and willing to plan and control their own actions. In such cases, the system is iteratively improved by actors' perceptions and insights. Koskela and Howell (2002) also argue that MaO is complementary with the language/action perspective, or LAP (Winograd 1986), in which organisations' coordination processes are primarily formed by commitments and promises between actors instead of explicit plans or commands, forming two-way communication and decision-making paths rather than the one-way paths emphasised under MaP.

Current practices in construction PP&C

Traditionally, researchers and practitioners have approached construction PP&C from the Platonian viewpoint, viewing production as a linear, predictable entity that can be planned by a central authority and then precisely implemented by a project or site manager who makes decisions on behalf of production crews (Turner and Cochrane 1993, Morris 1994). As a result, the development of the most widespread PP&C methods—such as the Critical Path Method (CPM; Kelley and Walker 1959), the Critical Chain (CC; Goldratt 1997) and the Line of Balance (LOB; Lumsden 1968)—have begun from the assumption of central management. Such approaches are explicitly designed to succeed in instances where production is perceived from the lenses of MaP (Johnston and Brennan 1996). Consequently, decision-making is often separate from the work itself, embracing a central viewpoint of management. Trade crews and individuals within them are often treated merely as executors of a predetermined plan rather than as independent decision-makers (Miller *et al*. 2002, Watkins *et al*. 2009, Priven and Sacks 2015), being disconnected from management decisions undertaken by the GC or client (Johansen and Wilson 2006, Laine *et al*. 2017).

Some have suggested, however, that construction production could instead be treated from the Aristotelian viewpoint, taking into account the complex nature of construction projects (Winch and Kelsey 2005). Several studies indicate that during production, decisions mostly evolve through the interdependencies, expertise and self-organized actions of crews and individuals (Sawhney *et al*. 2003, Watkins *et al*. 2009, Ben-Alon *et al*. 2014), which cannot be precisely planned or controlled by a single central entity (Winch and Kelsey 2005). As a result, scholars such as Ben-Alon *et al*. (2014) and Sacks and Harel (2006) suggest that construction production naturally evolves to favour decentralised management that takes advantage of the perceptions of crews. Construction crews also seem to be motivated to conduct independent and autonomous work, as long as adequate managerial preconditions are provided (Coffey 2000, Schöttle 2020). These notions necessitate questioning the usefulness of the dominant centralised approaches and inviting new, decentralised management practices (Bertelsen 2003, Yammarino *et al*. 2012) that will enable the autonomous decision-making of self-organized production crews and individuals within them (Janhonen *et al*. 2018).

Even though centralisation dominates current practice, scholars and practitioners have developed and successfully implemented various methods that emphasise decentralisation. Examples of these methods include the aforementioned LPS (Ballard 2000) and agile methods (e.g. Owen *et al*. 2006), which tightly integrate crews and individuals into the decision-making process, while managers act more as facilitators than authorities (Howell and Ballard 1998). These methods tend to actively focus on the social side of the process in addition to focussing on the technical result, which has often been the sole focus (Bølviken *et al*. 2015). It should be noted, however, that all the prevalent PP&C methods can be implemented in a centralised or decentralised manner, even though decentralisation has not been the focus of their development. For example, combinations of CPM and LPS (Huber and Reiser 2003), the Location-Based Management System (LBMS) and LPS (Seppänen *et al*. 2010), and takt production and LPS (Frandson *et al*. 2015) have all demonstrated promising results in combining the technical and social viewpoints in the PP&C process. In addition, methods such as LBMS and takt production can help to provide easily understandable visualisations of PP&C processes and outcomes (e.g. Seppänen *et al*. 2010), further aiding possibilities for collaboration and decentralisation.

Benefits and disadvantages of decentralised PP&C

The benefits of decentralised planning and control have been widely demonstrated in various instances

and across industries. Decentralisation has been connected to teams' and individuals' increased sense of ownership in operational decision-making (Mintzberg *et al*. 1976), enhanced performance in project and production management, accelerated development of skills and continuous improvement, improved conflict management (Humphrey *et al*. 2007, Yang and Guy 2011), enhanced short- and long-term proactivity and creativity (Grant and Ashford 2008), increased agility in responsiveness to changes and customer demands, better commitment to goals, and increased motivation and well-being of individuals (Mintzberg 1983, Richardson *et al*. 2002). In construction, the implementation of decentralised PP&C (through LPS, for example) has resulted in reduced process variability and waste with improved plan commitment, reliability (Priven and Sacks 2015), transparency, and project cost and time performance (Formoso and Moura 2009, Castillo *et al*. 2018).

While decentralisation is often seen as a mainly positive addition to planning and control practices that has several advantages, it also shows various disadvantages compared to centralised practices. Decentralisation may result in defects and inconsistencies in progress tracking (Barber *et al*. 1999), inadequate risk management and excess risk-taking (Lanaj *et al*. 2013), slow information flow and knowledge sharing (Mintzberg 1983), and coordination and communication problems amongst teams (Stinchcombe and Heimer 1985). These disadvantages are especially connected to situations in which adequate support and drivers for implementation are not provided (Salovaara and Bathurst 2018) and in the context of large-scale organisations in which the complexity involved in coordinating interdependent teams results in inefficiency (Drazin and Van de Ven 1985, Leavitt 2005). Salovaara and Bathurst (2018) note that, as with any new management style, the adoption of decentralisation often faces resistance while being both time-consuming and challenging to execute. In synthesis, centralised PP&C may advocate for better big-picture information flow and consistency, overall risk management, and mutual coordination, especially in large and complex multi-team contexts and situations where support for decentralisation is inadequate.

Drivers for effective decentralised PP&C

Several enabling drivers have been suggested in previous research within the general and construction management literature in order to succeed with decentralised PP&C and to overcome its possible disadvantages.

First, decentralised management calls for competence in adaptive decision-making and resilience (Bertelsen and Koskela 2005, Pikas *et al*. 2012, Saurin *et al*. 2013, Janhonen *et al*. 2018, Salovaara and Bathurst 2018, Martin 2019). The concept of resilience is often introduced in the context of managing complex systems (such as construction production) and denotes the ability to adjust and sustain systems' performance before, during and after the occurrence of changing conditions or disturbances (Hollnagel *et al*. 2006). Production crews and individuals need resilience to act in unexpected situations and to fill gaps between work-as-imagined (i.e. prescribed assumptions on how particular work is conducted) and work-as-done (i.e. how particular work is actually conducted). In complex systems, such gaps can be large (Soliman and Saurin 2020). Particularly in decentralised systems where crews and individuals have increased decision-making responsibility, increasing resilience by, for example, providing crews with scenario-based training and constant feedback in a real-life context is vital to maintain performance (Saurin *et al*. 2013).

Second, scholars have suggested the building of trust and transparency of information within and between crews and individuals within them as drivers of decentralisation (Coffey 2000, Baiden *et al*. 2006, Chinowsky *et al*. 2008, Saurin *et al*. 2013, Kärkkäinen *et al*. 2019, Martin 2019). Together, trust and transparency allow individuals to express themselves freely without being blamed or punished (Howell and Ballard 1998) and increase the capacity for informed decision-making (Manu *et al*. 2015). Loosemore (2014) states that by increasing trust and transparency, crews are more committed and can perform more effectively without the GC having to micro-manage their work.

Third, study findings have suggested that crews should be empowered to act autonomously in decision-making (Zábojník 2002, Bertelsen 2003, Saurin *et al*. 2013, Magpili and Pazos 2018, Pryke *et al*. 2018). Increased autonomy correlates with a high level of plan reliability and commitment (Sacks and Harel 2006), increased worker motivation (Zábojník 2002), an improved ability to succeed in unexpected situations (Desai and Abdelhamid 2012), increased diversity of the perspectives that drive innovation (Saurin *et al*. 2013) and the production system's internal capacity in general (Bertelsen and Koskela 2005). To support autonomy, Bertelsen (2003) and Raelin (2003) argue that the project/site manager's role should be

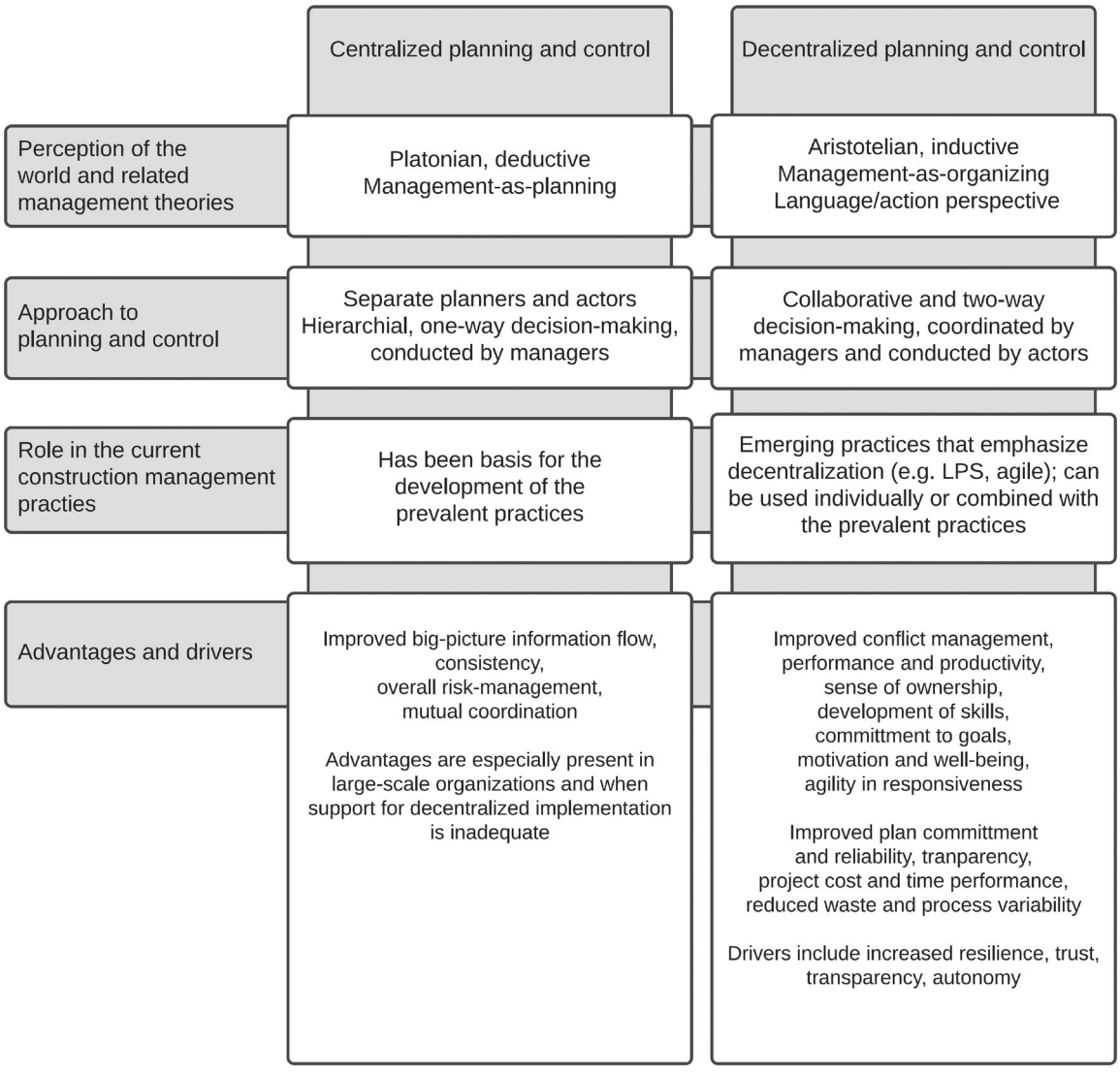

Figure 1. Synthesis of the theoretical background on centralised and decentralised planning and control.

transformed from a commander to a coach or facilitator who assists crews and individuals in providing the preconditions to perform their work.

Synthesis

Figure 1 presents a synthesis of the study's theoretical background. Even though centralised PP&C dominates construction management practices, implementing decentralised practices could be better suited for the needs of construction production. Indeed, methods that employ decentralisation have already been developed and successfully implemented. While decentralised PP&C offers several benefits, adequate drivers are needed for effective implementation. The literature suggests that both centralised and decentralised approaches have certain benefits and disadvantages, indicating that some suitable combination could be the most effective way to conduct PP&C.

Methodology

Research design

A comparative case study with a multi-method approach was employed to further evaluate how decentralisation/centralisation affects PP&C practices. The use of comparative case studies allows to investigate RQs in their real-life context (Yin 2014), thereby enabling systematic comparisons of two diverse viewpoints and drawing suggestions for possible improvement actions (Seawright and Gerring 2008). In this study, a single case consists of a production context of one construction project, including several subcases of work tasks formed around construction crews.

The case studies include two steps, in which both quantitative and qualitative research methods were used. First, a survey-based social network analysis (SNA) was conducted to objectively understand how communication and decision-making structures are formed during production, providing objective insights on the utilised PP&C practices. Second, semi-structured interviews were conducted with workers, crew leaders and site/project management to elucidate the SNA results and to explore the personal views of the project personnel towards PP&C practices. Schröpfer *et al*. (2017) and Pryke (2012) argue that by utilising such multi-method approach, researchers can address the complex and unique qualitative elements of construction projects while capturing the networks' quantitative aspects.

Case selection and descriptions

The case selection was subject to the following criteria. First, because a comparative evaluation of decentralised versus centralised PP&C approaches needed to be allowed, the cases had to represent both the centralised and decentralised approaches. Seawright and Gerring (2008) describe this strategy as a selection of the most different cases, which enables researchers to make stark comparisons between two approaches. They argue that to enable successful comparisons, cases must be comparable under a given dimension (in this instance, the approach to PP&C) while different enough to allow researchers to draw meaningful conclusions and make causal inferences. Kaarbo and Beasley (1999) note that the cases need not be comparable under every dimension, as long as they represent similar contexts (i.e. a construction production context). Second, the selected cases had to allow for the inspection of the production context as a whole but also specific crews and their work tasks; this approach allows researchers to understand how the production operates as a whole (Wellman and Berkowitz 1988) while enabling a focus on the specific PP&C of tasks that are studied as embedded subcases. Third, information-rich cases were preferred (Creswell and Clark 2017) that provided easy access to project information, documentation, site visits and project meetings, as well as the possibility of conducting SNA and interviews. The selected cases and work tasks had to be in progress during the data collection period to enable this scenario.

After the initial mapping of potential cases (which involved contacting and interviewing contractor and client representatives), two cases were selected from five candidates as most adequately fulfilling the study's criteria. The five candidates consisted of two clusters: two building and three infrastructure projects. The two building projects represented the decentralised approach, while the three infrastructure projects represented the centralised approach. A case from each category was then selected to enable comparative evaluation. Due to the availability of meaningful information and the need for access to settings where the whole production and several individual crews could be inspected, three of the cases were rejected, and a study set of two cases was ultimately established.

Case 1 is a commercial office renovation project in Espoo, Finland, that consists of the modernisation of a 25,000 m^2 space. Production is divided into four phases; at the time of data collection, the third phase was in the second half of completion. Case 1 project management and PP&C practices are characterised as decentralised, in which integrated project delivery (IPD) and "Big Room" working enabled partnering and collaborative decision-making with the client, contractors and designers. LPS is also used in PP&C processes. The studied crews, which primarily consisted of trade contractors' crew leaders and workers, operated with the following work tasks: (i) electricity works, (ii) ventilation and air conditioning (VAC) works, (iii) lock installation and (iv) painting. All the tasks were in progress during the data collection period.

Case 2 is a roadwork renovation project in Helsinki, Finland, spanning ~1.1 km of a two-lane street. The project includes the renovation of roads, traffic and municipal systems and the installation of new tram lines. The project is projected to span 2 years; at the time of data collection, the first of six production phases was halfway complete. Case 2 project management and PP&C practices are characterised as centralised, with design-bid-build (DBB) contracting and limited initiated collaboration in decision-making processes. The case has several clients, including the city and several owners of underground utilities, and their requirements are coordinated centrally by a construction management organisation and a GC. The specific PP&C method used in the case is undefined, but the approach contains elements from CPM and LBMS, operated through a heavily centralised approach. The studied crews, which consisted of both GC and trade contractor crew leaders and workers, operated with the following tasks: (i) earthworks, (ii) pipeworks #1 and (iii) pipeworks #2 (pipeworks were divided into two task sets, operated with separate crews). These were the primary ongoing tasks during data collection.

Table 1. Case descriptions and data sources.

	Case 1	Case 2
General description of the project	Commercial, renovation $\sim$ 25,000 m^2, 4 phases Located in Espoo, Finland	Roadwork, renovation $\sim$ 1.1 km of two lanes, 6 phases Located in Helsinki, Finland
Approach to project management and PPC	Integrated project delivery (IPD) with collaborative and decentralised decision-making / planning and control (Big Room and LPS)	Design-Bid-Build (DBB) with centralised decision-making / planning and control
Tasks related to the inspected crews' work	Electricity works Ventilation and air condictioning (VAC) works Lock installation Painting (*Majority of the work is operated by trade contractors*)	Earthworks Pipeworks #1 Pipeworks #2 (*Work is partially operated by GC and partially by trade contractors*)
SNA data sources	1 identification interview with site engineer Inspection of project documentation *organisational charts, meeting minutes, contact lists* 24 SNA survey responses	1 identification interview with project manager Inspection of project documentation *organisational charts, meeting minutes, contact lists* 29 SNA survey responses
Interview data sources	5 semi-structured interviews *I1/C1 (interviewee 1, case 1): site engineer (GC)* *I2/C1: electricity worker, partially acting as crew leader (trade contractor)* *I3/C1: painter, partially acting as crew leader (trade contractor)* *I4/C1: lock installer, partially acting as crew leader (trade contractor)* *I5/C1: project manager, VAC (trade contractor)*	8 semi-structured interviews *I6/C2: design manager (design consultant)* *I7/C2: responsible site manager (GC)* *I8/C2: site manager (GC)* *I9/C2: excavator operator 1 / worker (GC)* *I10/C2: excavator operator 2 / worker (GC)* *I11/C2: pipe installer / worker (GC)* *I12/C2: project manager (construction manager)* *I13/C2: project development manager (construction manager)*
Other data sources	3 site visits 3 site meeting observations Site meeting minutes Production schedules and organisational charts	3 site visits Site meeting minutes Production schedules and organisational charts

Data collection

Table 1 presents the case summaries and data collected in the study. In total, 15 interviews (in which two were identification interviews, further explained below) were conducted and 53 survey responses were collected; 24 survey responses and 5 semi-structured interviews are related to Case 1, and 29 survey responses and 8 semi-structured interviews are related to Case 2. In addition, supporting observation data was collected through several site and site-meeting visits and through the inspection of site-meeting minutes, organisational charts and production schedules. Data collection took place between November 2018 and April 2019. The data was consecutively collected first from Case 1 and then from Case 2.

Social network analysis

SNA was chosen as the first research method because it is suitable for analysing project communication and decision-making structures objectively and holistically in both numeric and visual terms (Chinowsky *et al*. 2008, Lee *et al*. 2018) while allowing the identification of relationship patterns and individuals' roles within networks (Pryke 2012, Zhang and Ashuri 2018). The approach can therefore provide insights into the centralisation/decentralisation of PP&C processes, knowledge about their effectiveness, and aids in determining how these processes can be most effectively managed and further improved (Priven and Sacks 2015, Poleacovschi *et al*. 2017).

Table 2 shows the relevant SNA observations for this study. The observations are drawn from two different categories: network structure and individual actor (node) attributes (Mead 2001). For network structure, findings related to tie characteristics, "factions," network density and power distribution were primarily considered. For actor attributes, findings about in- and out-degree centrality, closeness centrality, betweenness centrality and eigenvector centrality were considered. These actor-related observations were used to detect the individuals' roles in the network and are divided into three categories: group members/information consumers, liaisons/information hubs and authorities/"stars" (Freeman 1977).

In total, three different social network models were constructed for both cases. The first model considers

Table 2. Descriptions of relevant observations and their interpretation.

Domain	Interpretation
SNA Network structure analysis	
Tie characteristics	Ties reflect the quality and amount of communication between actors, divided into strong and weak ties. Strong ties represent a high amount of information exchange between actors, fostering effectiveness and exchange of tacit knowledge (Granovetter 1973). Even though a high amount of strong ties denotes effectiveness within a certain group of individuals, weak ties are also vital to disperse novel information outside of the core group, preventing group thinking and fostering long-term creativity (Hansen 2002).
Factions and network density	Factions denote a group of actors who share a relatively high amount of strong ties (Loosemore 1999), forming local, high density concentrations. High density correlates with smooth information flow within the faction, resulting in high team performance, trust and transparency (Chinoswky *et al.* 2008, Evans & Dion 1991).
Power Distribution	Denotes the distribution of authority within the network. Actors who make a large number of decisions and focus on distributing information tend to have more power over others (Chinowsky *et al.* 2010). In centralised networks the power is focussed on a few central actors, while in decentralised networks the power is distributed over factions and individuals.
SNA Actor attribute analysis	
Information consumer/group member	Information consumers are actors who do not actively contribute to information exchange or giving orders but mostly receive orders and focus on their own tasks. Often characterised by *low in-degree centrality*, indicating that they more likely receive than give or distribute information (Scott 2000). Also tend to possess *low closeness centrality* (indicating how closely an actor is connected to other actors) and/or *low betweenness centrality* (indicating how often an actor falls in the shortest path of information exchange between two random actors) (Loosemore 1999).
Information hub/liaison	Information hubs / liaisons are actors that most actively participate in coordination and problem-solving activities. Often well-connected and transfer information effectively across their peers that would be otherwise disconnected, while often producing creative ideas and sharing them with others (Burt 2004). Liaisons have high influence and power in the network. However, relying too much on them makes the network vulnerable when the actor is absent (Pryke *et al.* 2018). Liaisons are characterised by *high closeness centrality and/or high betweenness centrality*.
Information authority/star	Information authorities / stars are actors with a high amount of influence and power within the network. They actively control information flow and greatly participate in decision-making processes (Hickethier *et al.* 2013). These individuals are critical to the network's efficiency. Stars often have a *high in-degree centrality, high closeness centrality, and high eigenvector centrality* (indicates how well an individual is connected to other well-connected individuals) (Wasserman & Faust 1994).

general communication (information-flow networks: observations of tie characteristics, factions and network density), while the second considers decision-making (decision-making networks with observations of power structures). To gain a holistic view of the production, these models were constructed using a whole-network approach, where the unit of analysis is the whole production network (Wasserman and Faust 1994). The third network model considers crew and task-level communication (PP&C networks), divided into crew-specific subcategories. To analyse the crews' internal dynamics and individuals' influence in PP&C in more depth, this network model was constructed using an "egocentric" approach, where the unit of analysis is specific work tasks and their related crews (Wasserman and Faust 1994).

In all three models, nodes represent individual actors. In information-flow and PP&C networks, the edges represent two-way communication between actors; in decision-making networks, the edges represent one-way commands from one actor to another in order to address power structures. Boundaries for the analysis were set to include all actors who had a relevant effect on production during data collection, including site personnel, designers, GC and client representatives, material suppliers, etc. The rough boundaries were set by the researchers (using the nominalist approach) and iterated with case actors

using the realist approach, further explained below (Laumann *et al*. 1989).

Guided by Chinowsky *et al*.'s (2010) approach, the data for SNA was collected in two steps, in which the initial identification of the relevant actors was followed by primary data collection through a survey. First, the initial identification of the relevant actors was achieved by analysing project documentation (such as organisational charts) and conducting a single structured identification interview with a project representative (e.g. project manager) who had a holistic view of the most relevant actors. This initial identification allowed to draft rough social networks that then formed a basis for identifying and engaging the relevant actors with the survey. The following questions were asked during the identification interviews:

Information-flow and decision-making networks:

- 1a. Which project participants are relevant for the production at the moment?
- 1b. How do these project participants communicate with each other (intensity, forms of communication)?

PP&C networks:

- 2a. Which project participants are relevant for the task at the moment?
- 2b. How do these project participants communicate with each other (intensity, forms of communication)?

Second, the primary data was collected through a survey. Surveys are widely adopted instruments for data collection in SNA studies (Chinowsky *et al*. 2010, Schröpfer *et al*. 2017). A survey is a flexible way to collect data (compared to analysing databases or email logs, for example) and has a more standardised structure compared to qualitative methods such as interviews (Nardi 2006). In the survey, the participants were asked to identify their communication and decision-making patterns regarding the case and the work tasks under observation. The participants were given an option to complete the survey in either electronic or paper form due to access restrictions; some participants (e.g. particular designers working in distant locations) were unable to physically fill in the forms, while others (e.g. particular workers) lacked direct access to computers or smartphones. The participants could choose either the Finnish or English version of the survey. The researchers provided active guidance for participants as any questions about the survey arose. The survey was sent to all 68 actors who were identified in the two cases; in total, 53 completed surveys were obtained, for a 78% response rate.

During the data collection period, it was noted that not all the participants who had initially been identified could be considered relevant for the production context. After these participants had been contacted to fill out the survey, they stated that they were not actively involved in the current stage of production. These participants included sales personnel or personnel involved in the project only in previous phases, for example. Thus, it was justified to omit these participants from the survey, concluding that the responses obtained were adequate to form social networks for meaningful analysis.

The survey consisted of five sections: (i) general information, (ii) questions about general communication (the information-flow network), (iii) questions about power structures (the decision-making network), (iv) questions about specific work tasks related to the crews (PP&C networks) and (v) open-ended questions about decision-making (to qualitatively broaden and support the interview data). The survey is presented in Appendix 1. The questions were presented in free-recall and free-choice format to enable participants to identify the actors they communicated with without predetermined restrictions. This approach allowed the participants to have freedom in their responses and to identify new actors, thus diminishing the possible biases of the initial identification stage (Wasserman and Faust 1994). The survey takers were provided with choices to determine communication modes (email, project document bank, phone, face-to-face, meeting, other) and for communication intensity. A five-point Likert scale, which is often used in survey-based SNAs (Hatala 2006), was employed to examine communication intensity more widely than with a binary scale while providing more tangible choices for participants than with a sliding scale. The score intensity was multiplied for the analysis as follows:

1. Seldom (once or twice per month) = edge weight 1.0;
2. Irregularly (a few times a month) = edge weight 2.0;
3. Regularly (once or twice a week) = edge weight 4.0;
4. Often (several times a week) = edge weight 10.0;
5. Daily (at least once a day) = edge weight 20.0.

The survey form was similar for everyone, but in section iv, the attendees were guided to focus on those subsections related to the specific work tasks which they had directly or indirectly participated. The survey forms were collected, combined in Excel and then pseudonymized; Gephi software (version 0.9.2) was utilised to construct the data into sociograms and to calculate the desired metrics. A force-directed layout (the Force Atlas algorithm) was used to enhance visualisation in Gephi.

Interview process

In total, 13 semi-structured interviews (Table 1) were conducted to understand how individuals perceived the PP&C practices in use. Semi-structured interviews were employed to allow interviewees to express themselves freely while still having a structure to guide the discussion towards the RQs. Even though the interviews followed a pre-set structure, the interview process was affected by the flow of the conversation and the interviewees' expressions.

Interviewees were selected to cover two categories. The first category included project personnel in management and vital decision-making roles, such as project and site managers. The second category consisted of crew members such as crew leaders and workers, selected to cover every studied crew and its related work task. The participants for the semi-structured interviews were selected based on the initial identification interviews (see the previous chapter). In the first category, personnel with numerous strong ties within the project/site organisation who also had managerial roles in the project were preferred in the selection; in the second category, it was ensured that at least one person from every studied crew was interviewed.

The interviews were structured with five themes: (i) general questions and reflections on SNA results, (ii) general communication, (iii) PP&C practices, (iv) possible improvement actions and (v) ending notes. In theme iii, different questions were weighted for interviewees based on their category. The interview form is presented in Appendix 2. The interviews were recorded verbatim and transcribed, but the quotes presented in the findings section have been translated from Finnish and lightly edited for clarity in English.

Data analysis and synthesis

Data analysis/synthesis was conducted in four steps. First, a preliminary SNA consisting of visualisations was conducted to support and guide the interview process. Second, the social networks and interviews were analysed separately on a case-by-case basis. Both social network and interview analyses were deductively guided by the RQs (Creswell and Clark 2017) while seeking points of similarity/difference or new information. The previously transcribed interview answers were first structured and labelled in a spreadsheet by cases, interviewees, interview themes and interview questions. The interviews were then interpreted by looking for recurring themes and sub-themes, similarities and contrasting opinions, and emerging relationships between answers (Miles and Huberman 1994). The main author conducted the first two steps, which formed a base for further analysis and discussion between authors. Third, SNA and interview results were combined within cases to gain a holistic understanding of the cases (Yin 2014). The SNA and interview findings were also triangulated with the supporting data (Table 1) to gain support for the most prevalent findings and to explore possible new viewpoints that were not evident from the primary data sources. This step was followed by comparative case analysis, in which similarities, differences and complementary points of the centralised/decentralised PP&C approaches were sought, thus forming a basis to interpret the RQs. Finally, the results were discussed in light of the literature and RQs, leading to a formulation of conclusions, study contributions and suggestions for future research avenues.

Findings

General communication and power structures

The general communication patterns were analysed through information-flow networks, illustrated in Figure 2. Regardless of the PP&C approach, strong ties and dense network structure within the site indicated trust and transparency of communication in both cases. Factions with strong ties were formed between groups with frequent access to face-to-face communication, primarily around work tasks and site managers. Designers, client representatives and material suppliers were mostly connected to the site organisations through site managers and crew leaders via weaker ties.

In Case 1, which used the decentralised PP&C approach, the GC's site managers acted as primary information liaisons, distributing information between project participants and the site personnel. Trade contractor crew leaders formed secondary information hubs, acting as links between managers and workers while also communicating actively together; they showed high values for betweenness, closeness and eigenvector centralities (Figure 3). Communication factions were primarily formed around work-specific crews. No significant

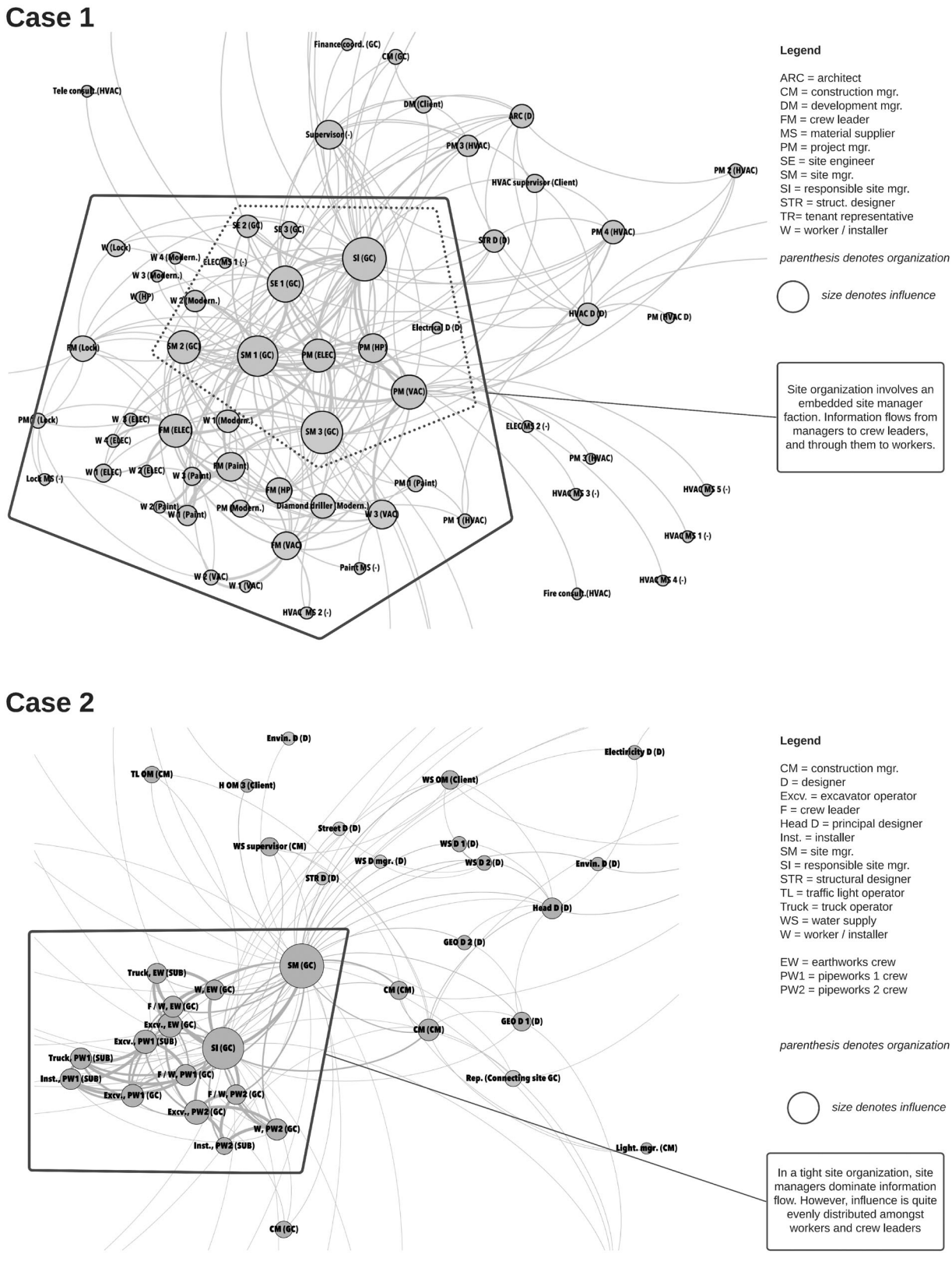

Figure 2. Case 1 and Case 2 information-flow networks.

information bottlenecks were noted, although the project organisation seemed to have a certain hierarchy of managers, crew leaders and workers, despite the decentralised approach to management.

In Case 2, which used the centralised PP&C approach, site managers and tight task-specific crews consisting of crew leaders and workers formed the primary communication factions (Figure 2). Compared to Case 1, the site

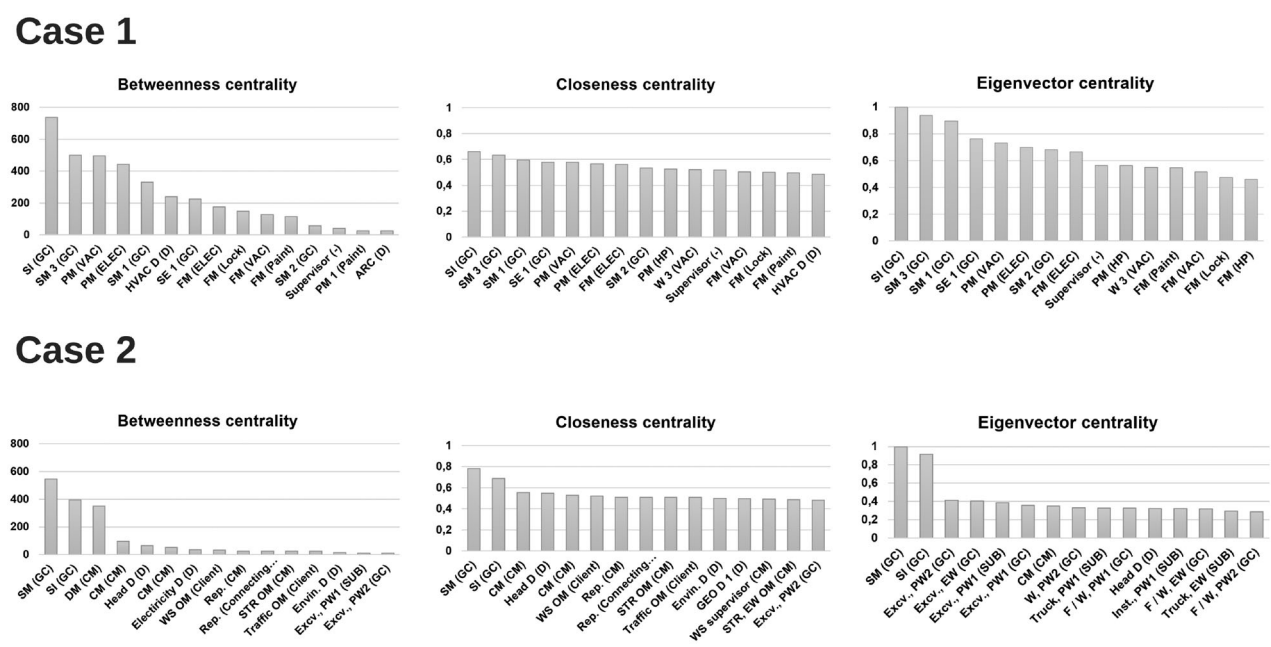

Figure 3. Case 1 and Case 2 information-network betweenness, closeness and eigenvector centralities.

managers' role as information liaisons seemed to be significantly more comprehensive, with high betweenness and eigenvector centrality measurements (Figure 3). Beyond the managerial level, however, the information flow seemed to be relatively evenly distributed amongst crew leaders and workers, who seemingly had an equal role as information liaisons and consumers. This finding, quite surprisingly, contrasted with the situation of Case 1, where crew leaders had a seemingly dominant role in information distribution compared to workers, despite the decentralised practices in place.

The power structures, analysed through decision-making networks, shared similar patterns as the general communication. Regardless of the PP&C approach, site managers were identified as primary authorities (high in-degree and closeness centrality), having a dominant role in distributing information and having authority over general decision-making. In Case 1, the decision-making power was relatively evenly distributed amongst site managers and crew leaders. In Case 2, the power was centralised to site managers. Below managers, however, the workers seemed to have a certain amount of autonomy (shown in evenly distributed in-degree centrality) compared to Case 1.

Managers' personal perceptions of PP&C

The data from the manager interviews supported the findings from the communication and decision-making network analysis; regardless of the approach, all the interviewed managers reflected on having a critical role in information distribution and having a vast amount of decision-making responsibility. Client representatives and project managers felt they had control of the overall schedule (Interviewee [I]12/Case [C]2 and I13/C2). Site and trade contractor managers felt they had control of and responsibility for phase schedules and site progress (including resourcing, design management and logistics management) while taking input on PP&C from designers, managers and client representatives in weekly/monthly meetings and from crew leaders and workers in daily conversations (I01/C1, I05/C1, I06/C2, I07/C2, I08/C2).

Between the cases, the most prevalent differences came from the perception of how managers felt about collaboration. In Case 1, even though they felt they had certain decision-making responsibilities, the interviewees also expressed the importance of the collaborative input of production crews in PP&C (I01/C1, I05/C1).

> I05/C1 [Project manager, VAC]: *We work things out together* [with site management and crew leaders]. … *The crew leaders have the best awareness of the production status, and we often do the* [three-week] *look-ahead and weekly planning together.*

In Case 2, the long- and short-term plans were perceived to be primarily orchestrated by the project and site management (I07/C2, I08/C2, I12/C2). Even though managers reflected on taking suggestions from crew leaders and workers, they felt that the decisions were mainly made in a centralised manner.

> I07/C2 [Responsible site manager]: *The workers always have their viewpoint* [on how to conduct work] … *of*

course, we listen to their opinions, but managers always have the responsibility in actual decision-making.

PP&C structures

In both cases, compared to the information-flow and decision-making networks, the predominant roles shifted within the PP&C networks. In Case 1, crew leaders took a prominent role in task-level PP&C (with high values for closeness, betweenness and eigenvector centralities), followed by workers, project managers and site managers. Particularly regarding the PP&C of the electricity, locking and painting tasks, crew leaders dominated as liaisons/stars. Within crews, the PP&C activities were managed centrally through crew leaders, as they dominated information flow between crew members, site management and other site crews. This finding indicated certain limitations in information transparency that formed a possible bottleneck for effective communication.

A similar shift of liaison and star roles was partially present in Case 2, but from site managers equally to the whole task-specific crew. Compared to Case 1, the PP&C information flowed more freely within the crew, indicating decentralisation with a large amount of trust and transparency. The crew members acted equally as information liaisons and consumers, thus supporting the information-flow network analysis findings. Site managers still partially remained central authorities, and they were primarily responsible for communication from the site to other project participants. Figure 4 illustrates the PP&C networks for electricity works (Case 1) and pipeworks 1 (Case 2).

Production crews members' personal perceptions of PP&C

Regardless of whether a centralised or decentralised approach was used, the interview findings of the production crews supported the responsibility shift observed from whole networks to PP&C networks. In contrast to the managers' perception, in both cases, crew members felt they had a vast amount of responsibility and autonomy towards PP&C coordination, especially on weekly and daily activities. In Case 1, crew leaders and workers generally felt that even though project and site managers were responsible for large-scale decisions, during production, most decisions about PP&C (including coordination with other crews, task execution and resource management) were coordinated primarily by crew leaders and also partially by workers (I02/C1, I03/C1, I04/C1). The crew members felt that crew leaders had the best overall understanding of the production status, thus supporting the SNA findings. For the crews, Case 1's site managers were not viewed as decision-makers but more as information hubs and facilitators, and they often provided requirements about plan progression that were collaboratively discussed and then refined by crews, led by crew leaders (I02/C1, I03/C1, I04/C1).

> I02/C1 [Electricity worker, partially acting as crew leader]: *I make decisions about the work order for electrical work regarding the whole worksite.*

> I03/C1 [Painter, partially acting as crew leader]: *Site managers pass on a large amount of information, but they aren't that involved in daily or weekly decisions. I make most of the decisions regarding planning and control on the site … I feel that I can contribute as much as I want. And I also try to involve other workers in the decision-making as much as I can.*

> I04/C1 [Lock installer, partially acting as crew leader]: *Well, in fact, nobody does the planning for me. I'll do it on the run and apply as needed.… I'll make all the decisions about the workflow, and then guide other workers.*

Many workers felt that they had adequate room for their own PP&C decisions in Case 1 (open-ended survey questions).

> [Painter 1/C1]: *I make decisions on the order of work every day, deciding on the work stages and the order of floors and rooms.*

> [Electricity worker 1/C1]: *I make decisions on the final placement of the furnishings (every week), cable routes (every week) and fixing/updating of insufficient electricity plans (every month).*

Similar results were found in Case 2, with the difference that the responsibility of weekly and daily decisions not only primarily lay with crew leaders but also equally with workers (I09/C2, I10/C2, I11/C2). While in Case 1 the collaborative PP&C was primarily initiated through weekly LPS meetings that included managers and crew leaders, in Case 2, the collaboration was more deliberately extended to include all production crew members (also observed from the supporting documents). The workers also felt they had the best overall understanding of tasks' weekly, daily and production progress. Even though site managers had a certain central authority and were responsible for managing the overall schedule and supporting tasks such as traffic coordination, workers felt that they played a significant role in adjusting and coordinating weekly and daily task-level work. The interviewees saw tight collaboration and adjustment between site managers and crews as necessary for success. They also

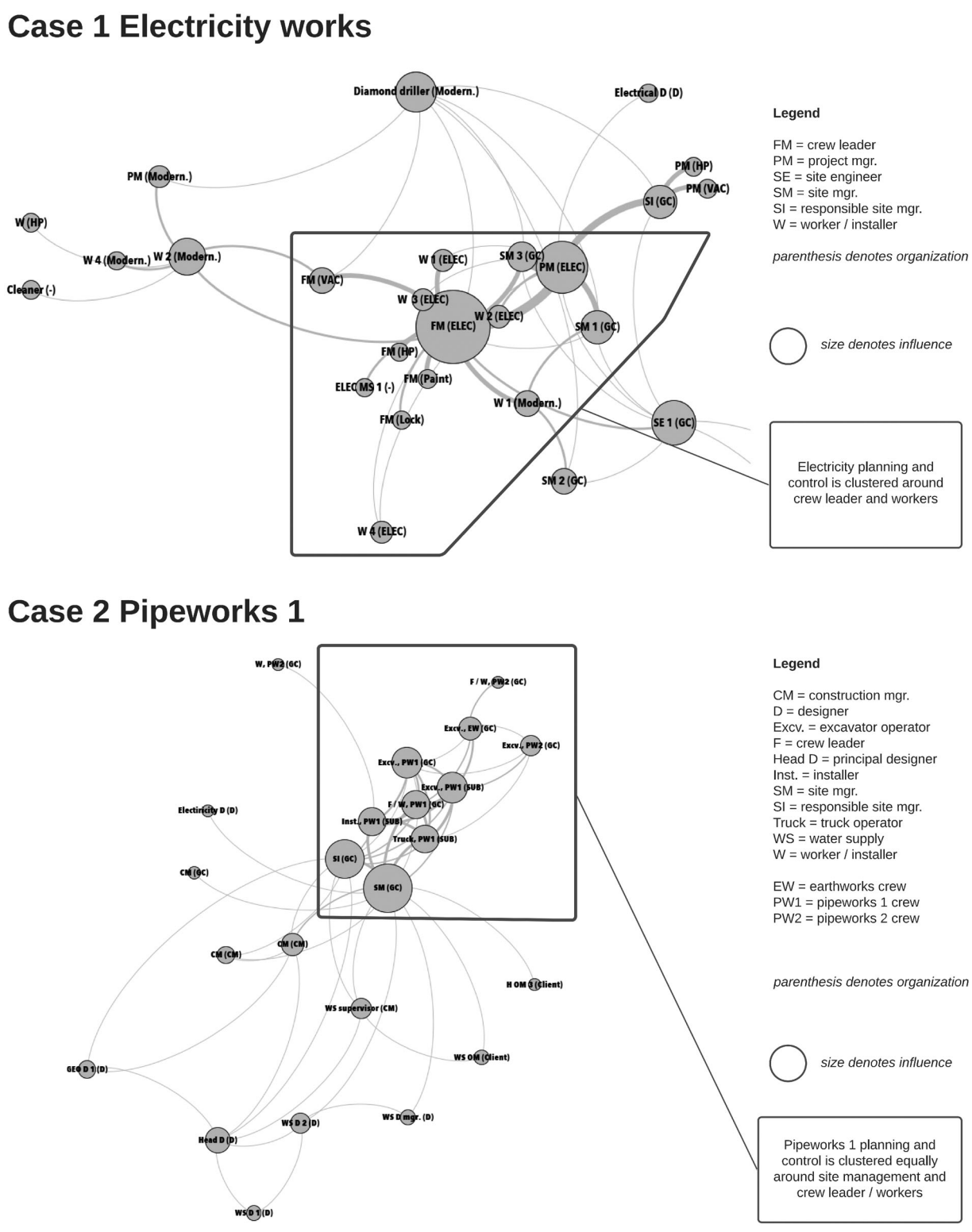

Figure 4. PP&C networks of electricity works (Case 1) and pipeworks 1 (Case 2).

emphasised the importance of adequate transparency in and between crews, which enabled the workers to control their daily work semi-autonomously (I09/C2, I10/C2).

I09/C2 [Excavator operator]: *I make daily decisions on the work order and general organization of work … I like the independence … site managers have a lot to coordinate, so it's also reasonable to decentralize the authority.*

> I11/C2 [Pipe installer]: *Daily and weekly decisions* [about work execution] *are made in tight collaboration with site managers and other workers … however, if everything's clear, the management doesn't have to intervene in my decisions.*

Regardless of the case, the crew leaders and workers were not frustrated with having this seemingly large role in PP&C; rather, they seemed to feel that having the responsibility was a sign of a smooth and collaborative production process. The crew leaders and workers also seemed to have a large amount of control over design and material management (I02/C1, I03/C1, I04/C1, I09/C2, I11/C2). The detailed design was done in parallel with production in both cases, while crew leaders and workers also largely contributed to the final designs. On the other hand, crew leaders and workers did not necessarily desire to be involved in every decision, such as in overall coordination; instead, they were primarily interested in contributing to areas that were directly connected to their work.

> I02/C1 [Electricity worker, partially acting as crew leader]: *The designer doesn't run the designs for the accuracy that's needed on the site … in lots of cases, we make suggestions for the designer, who then approves them.*

Perceived drivers and advantages of decentralisation/centralisation

The interviewees saw the various drivers for decentralisation as being beneficial for PP&C in general, regardless of the approach, although the drivers emerged differently between the cases and also resulted in different advantages and variability in performance. In Case 1, the interviewees perceived the collaborative contracts/delivery method, the Big Room concept and decentralised PP&C methods as providing transparency and the ability to sustain their performance when problems or disputes arose (indicating resilience), especially amongst managers in the phase-planning stage. They also viewed these methods as enabling tighter coupling of designers, client representatives and the site organisation (I01/C1, I05/C1). Interviewee I02/C1 also mentioned that earlier collaboration in previous projects with the GC and other trade contractors had increased initial trust. The implementation of the above-mentioned practices enabled process-oriented and agile conflict and change management, in addition to a commitment to mutual production goals (I03/C1). The interviewees mostly mentioned having a sound sense of ownership over the process (indicating autonomy in decision-making), although this only seemed to apply to managers and crew leaders. These above-mentioned advantages were seen to positively contribute to schedule performance (I4/C1, I5/C1), and during the data collection period, the project was on time despite the tight initial milestones.

In contrast, in Case 2, most of the interviewees (I06/C2, I07/C2, I08/C2, I10/C2, I11/C2) argued that DBB as a delivery method was relatively rigid, and the information flow between the design and production phases, and between organisations, was somewhat inadequate (I12/C2). The Case 2 interviewees generally admitted that the above-mentioned issues indicated a large gap between work-as-imagined and work-as-done, which in addition to having demanding site conditions and an initially tight schedule created certain stress for site personnel. They did perceive transparency of information, trust and the ability to solve unforeseen problems (indicating resilience) within the tight site organisation to be excellent, however; these factors developed during the production when managers, crew leaders and workers had to continuously tackle emerging problems together (I08/C2, I09/C2, I11/C2). The interviewees perceived this scenario to have resulted in gradually increased performance in production control and a strong sense of autonomy within production crews, albeit simultaneously resulting in dependability on the performance of key site personnel (particularly site managers) in managing risks and communication outside the site. During the data collection period, the project was slightly behind the initial schedule, but the site personnel were generally positive about being able to meet the upcoming milestones on time (I7/C2, I8/C2, I10/C2, I11/C2).

Improvement suggestions for PP&C practices

Several interviewees from both categories and both cases felt that if crew leaders and workers were included in PP&C decision-making more intensively and earlier, then several other aspects of the project (e.g. design management, scheduling, work structuring and resource management) would be improved (I02/C1, I03/C1, I05/C1, I07/C2, I08/C2, I11/C2, I12/C2).

> I12/C2 [Project manager]: *Designs and plans should also be done to serve workers, not only authorities … to improve, the involvement of crew leaders and workers in* [the early] *design and planning stages is critical.*

But even though the interviewees saw the decentralisation of practices as having potential, participants

from both cases also argued that some aspects of PP&C (such as large-scale planning decisions, coordination between projects and larger material orders) could be adequately handled with centralised management (I02/C1, I09/C2). In addition, the current industry culture did not seem to support a radical increase in decentralisation (I03/C1, I11/C2).

> I03/C1 [Painter, partially acting as crew leader]: *I think it would be beneficial to involve the people who actually do the work* [in decision-making]. *But I don't know if they'd actually listen to my opinions …*
>
> I11/C2 [Pipe installer]: *Of course, it would be useful to involve workers to contribute more in planning … but the system is what it is. I don't know how it could be changed.*

Other suggested improvements, most of which considered an increased proportion of decentralisation, included allocating more time for individual workers' work planning, involving workers more deeply in decision-making procedures, allocating more time to training individuals to cope with decision-making responsibility, and officially determining and recognising individuals' responsibilities in places where their roles were not currently visible (I04/C1, I06/C2, I11/C2). In addition, one interviewee believed contracts should better address the needs of networked processes; currently, the capacity needed for crew leaders' and workers' work planning was not recognised or rewarded adequately (I03/C1). In the same vein, crew leaders and workers felt that the schedulers and managers did not sufficiently recognise the quantity of decisions, coordination and corrective actions that were actually needed in the daily and weekly PP&C currently performed by crew leaders and workers. This resulted in increased workload generally but also underutilisation of their skills in the formal PP&C process, despite the managers' recognition of the need for worker involvement at some level (I02/C1, I03/C1, I09/C2).

Discussion

In this chapter, RQ1 *How do decentralisation/centralisation affect construction PP&C practices when considering both the production crew and manager perspectives?* is first discussed in sections 5.1 and 5.2, followed by discussing RQ2 *Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?* in section 5.3.

The gap between managers' and crews' perceptions hampers PP&C effectiveness

The study results indicate that regardless of the chosen approach towards PP&C—in other words, whenever management is approached from the viewpoint of autocratic planning (MaP; Johnston and Brennan 1996) or autonomy-driven organising (MaO)—both Platonian and Aristotelian paradigms were present. From the viewpoint of production crews, the observations from both cases supported the presence of an Aristotelian, inductive paradigm, as production seemed to emerge as dynamic and decentralised (Ben-Alon *et al.* 2014). The crew members felt primarily responsible for operational decisions, quantitatively making a majority of the decisions autonomously in a decentralised manner (supported by the PP&C network analyses, and also noted by Pikas *et al.* 2012). The crew leaders and workers had autonomy in planning and controlling their work (also noted by Bertelsen 2003) and did not seem to be frustrated with this vast amount of responsibility but primarily appreciated the possibility to contribute. Weekly and daily (i.e. micro-level) PP&C activities were largely based on face-to-face, two-way communication and individuals' commitment in tight site factions, rather than explicit orders (i.e. the language/action perspective; see Winograd 1986). These findings furthermore support the presence of MaO, in which individuals are motivated and capable of affecting their work, possessing an inherent drive for autonomy (also noted by Coffey 2000, Schöttle 2020).

In contrast, from the managerial perspective and amongst formal and phase (i.e. macro-level) planning processes, centralisation and hierarchical structures were present in both cases (indicating the presence of the Platonian, deductive paradigm). Partially in Case 1 and especially starkly in Case 2, which was categorised as centralised, managers felt they had (and also objectively seemed to have) a vast amount of responsibility and authority over decision-making. Even though in Case 1 the decentralised practices partially enabled the extension of formal PP&C decision-making to crew leaders, recognition of the workers' involvement was primarily missing from the managerial viewpoint.

These strong differences in perceptions towards PP&C between managers and crews—which occurred regardless of the employed approach– require increased attention. Even though both sides' viewpoints are justified, this contradiction in epistemological understanding of production's nature surfaces problems for further improving PP&C practices. As

Johansen and Wilson (2006) point out, overly differing perceptions towards the epistemology of production is one of the most critical barriers to building effective PP&C. If managers do not acknowledge a crew's role as a vital decision-making entity, then the PP&C practices will more likely continue to be built upon overly centralised and sub-optimized practices. If managers perceive production solely from the Platonian viewpoint, they cannot be fully aware of recurring daily problems, thus increasing the gap between work-as-imagined and work-as-done (Soliman and Saurin 2020), which will then further require an increased amount of resilience from the crews to not feel extensively overwhelmed or burnt out by their micro-level decision-making responsibilities (Salovaara and Bathurst 2018).

Despite having a certain feeling of autonomy, the crew leaders and workers simultaneously felt that the critical roles of crews in operational PP&C were not recognised, resulting in a lack of time, resources and support in decision-making, which further led to ineffectiveness, reactivity and increased stress. In this kind of environment, the site crew will most likely be unable to utilise their expertise in macro-level decisions, which will also lead to the waste of unused talent. Although addressing this gap between the perceptions is crucial for improving PP&C practices, its presence is not very surprising, as the dominant management practices (such as CPM) have been built and advanced primarily from the Platonian viewpoint and only take into account the managerial viewpoint (Johnston and Brennan 1996).

Decentralised PP&C offers several advantages proactively, but does not take workers into account

Differences between the approaches were also noted. The first notable difference is that the decentralised approach to PP&C seems to yield several advantages over centralised PP&C that are primarily in line with those presented in the theoretical background section, also resulting in improved schedule performance. In Case 1, despite the partial presence of hierarchies, the approach allowed decentralisation on the managerial level and between crews, in which managers also acted as facilitators. Simultaneously, crews made their own decisions, which were orchestrated by the crew leaders. As an outcome of implementing decentralised PP&C, the SNA results show increased transparency in the whole supply chain (indicated by the high amount of strong ties and smooth information flow), while the interview results show increased capability for conflict management between site crews and project stakeholders (see also Humphrey *et al.* 2007, Yang and Guy 2011), increased proactive commitment to mutual goals (Priven and Sacks 2015) and lower stress (Mintzberg 1983). In contrast, in Case 2, PP&C was dominated by the managers making decisions, which positioned them as critical individuals for successful information and decision-making flow (within the site and towards off-site stakeholders), thus creating opaqueness to the production process. This setup made the process more vulnerable to distortions and dependent on individuals at the site, which created a certain reactiveness to PP&C practices.

The results indicate that the presence of the suggested drivers (resilience, transparency/trust, autonomy) aid successful PP&C regardless of the managerial approach taken. As a second notable difference, with the decentralised approach the drivers for success are built proactively on an organisational level, are more process-based, and emerge with more ease. With the centralised approach, drivers seem to emerge from the urgency to cope with problems the site crew encounter. Thus, even though drivers are eventually achieved with both approaches, the decentralised approach seems to be better suited for systematic and collaborative capacity development, as also noted by Yang and Guy (2011). A successful centralised approach seems to require strong and experienced individuals who can perform under stress and manage production with less overall support, thus increasing the system's vulnerability. The proposed benefits of the centralised approach, such as good large-scale information flow and mutual coordination (Mintzberg 1983), were present in both cases, although with the centralised approach they seemed to depend on capable individuals in key managerial positions and their ability to build the drivers reactively during production.

The third notable difference between the approaches is how the production crews' internal dynamics and PP&C responsibilities within crews materialise. Even though the approaches primarily emerge on the overall production level as indicated by the theoretical background, the used approach had a contrary than intended effect for the crews' internal dynamics. Despite employing the decentralised approach, in Case 1, crew leaders dominated the micro-level decisions, forming centralised PP&C structures within crews; the responsibility was shifted from managers to the crew leader, but other crew members were still excluded from the process. A sense of ownership of PP&C was present (Mintzberg *et al.* 1976) but

primarily applied only to the managerial and crew leader levels. Thus, while the decentralised approach demonstrate various benefits, it is not (at least in its applied form) able to capture or improve the necessary aspects of production crew members' needs, enabling decentralisation only in a limited way. These effects were primarily observed from the PP&C networks and crew interviews, and they indicate that the current PP&C (and other collaborative practices, such as collaborative delivery models) do not necessarily affect crews' internal dynamics and micro-level PP&C, even though that could have made a welcome addition to improving PP&C effectiveness. In contrast, with the centralised approach, it was surprising how evenly the decision-making responsibility was distributed within crews, despite the presumption that the approach was expected not to allow workers to have a large amount of freedom in their own decision-making (e.g. Johnston and Brennan 1996). Even though managers possessed a vast amount of autocracy, the crew members were able to gain almost equally distributed responsibility with crew leaders in PP&C above the managerial level.

The results indicate that even though aiming for decentralisation, methods such as LPS might smother the voice of the workers with their extensive focus on project managers and crew leaders, namely "last planners", as also indicated by Pikas *et al.*'s (2012) results. This scenario might increase rather than decrease the gap between epistemological perspectives towards PP&C practices, leading to an inability to solve the problems brought up in the previous chapter. Also suggested by the benchmark of LPS development, one possible development action of the method is to extend the involvement from crew leaders to the worker level (Ballard and Tommelein 2016), which would seem an adequate action for improving decentralised PP&C.

Improvement suggestions

Regardless of the managerial approach taken, the improvement suggestions for better PP&C generally involve more deliberate decentralisation, stemming with the vast amount of observed benefits in the literature and the study findings that decentralised PP&C could bring.

To diminish the gap between managers' and crews' perceptions towards PP&C and improve overall PP&C capabilities, recognition of a crew's tacit responsibilities and internal dynamics (as also noted by Chinowsky *et al.* 2008) should be embedded in formal PP&C processes. Brought up especially in the workers' and crew leaders' interviews and supported by studies in the literature (e.g. Saurin *et al.* 2013), more intense involvement of crew leaders and workers in planning, officially determining their responsibilities in operational decision-making, and allocating more time and providing training for role-based planning should be considered as improvement initiatives. Particular attention could also be paid to training site managers to ensure that they can effectively perform as facilitators, which would require a partially renewed skill set (Bertelsen 2003).

The drivers presented in the theoretical background were seen to be beneficial for the production, regardless of the degree of intended decentralisation. Deliberately building resilience (Saurin *et al.* 2013); increasing trust by providing support for team-building with face-to-face communication (Chinowsky *et al.* 2008), particularly if the team has not worked together beforehand; ensuring adequate transparency through visible information flow (Kärkkäinen *et al.* 2019); and providing ownership and a sense of autonomy for all crew members over operative decisions (Bertelsen 2003) all provide preconditions for success. In addition to improving the above-mentioned project-level capabilities, these development actions should also reach the level of cultural change (also see Teräväinen *et al.* 2018).

But although increasing the amount of decentralisation and an emphasis on the Aristotelian viewpoint of PP&C seems to be favourable, Koskela *et al.* (2019) note that instead of purely opting for an either fully centralised or decentralised approach, a fine balance between the two is usually necessary for effective management. In addition to driving the above-mentioned suggestions, centralisation might be necessary in aspects such as project-level coordination and risk management (suggested by the interviewees and Lanaj *et al.* 2013), at least in short-term implementation initiatives and given the prevalent cultural environment.

Conclusion, limitations and avenues for future research

Conclusion and study contributions

This study has explored the effects of decentralisation (and for contrast, effects of centralisation) for construction production planning and control (PP&C) from the combined perspective of production crews and managers, in order to utilise these viewpoints to provide improvement suggestions for construction PP&C practices. To achieve holistic assessment, the research was

conducted as a multi-method comparative case study using survey-based social network analysis (SNA) and semi-structured interviews.

From a theoretical perspective, the study increases the field's understanding of the differences and similarities of decentralised and centralised PP&C while considering the diverse perspectives of both managers and production crews. To answer the first research question *How do decentralisation/centralisation affect construction PP&C practices when considering both the production crew and manager perspectives?* production crews tend to perceive PP&C as dynamic and decentralised, while managers' perception is geared more towards the existence of hierarchical and centralised structures, regardless of the approach that is used. If not addressed, this gap between the perceptions will continue to form barriers for building effective PP&C practices, including overly centralised, managerially led practices; large gaps between work-as-imagined and work-as-done; site crews feeling overwhelmed and stressed; a lack of time, resources and support in crews' operational decision-making; and the waste of unused talent.

Several differences also exist: the decentralised approach offers several benefits—such as providing transparency in the supply chain, the capacity to resolve conflict, commitment to mutual goals and lower stress—while allowing a proactive building of necessary drivers such as resilience, increased transparency/trust, autonomy and feeling of ownership, all of which are necessary, regardless of the managerial approach taken. These drivers lead to efficient and process-oriented PP&C. The effects of decentralisation, however, do not directly reach the worker level in the used practices, which indicates that the current PP&C practices do not consider the production crews' internal dynamics very effectively but are instead limited to the managerial and crew leader levels, hampering reaching the full potential of decentralisation.

For practitioners, the study provides suggestions about how construction production could be more effectively managed by taking into account the possibilities of both decentralised and centralised planning and control. Considering the second research question *Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?* the suggestions are summarised as follows:

Suggestions related to decentralisation include

1. Recognising a crew's tacit responsibilities and internal dynamics and embedding them in formal PP&C processes;
2. Ensuring the earlier and more intense involvement of crew leaders and workers in planning, officially determining their responsibilities in operational decision-making, and allocating more time and resources for their individual PP&C;
3. Providing training for role-based PP&C, both for crew leaders and workers but also for managers to act as facilitators;
4. Providing support for building resilience, increasing trust with team-building and face-to-face communication, and supporting adequate information transparency;
5. Ensuring ownership of decisions and a sense of autonomy for crews; and
6. Developing cultural change towards the recognition of the benefits of decentralisation.

Suggestions related to centralisation include

7. Ensuring project-level alignment with central coordination;
8. Ensuring overall risk management with central risk assessment and coordination.

The improvement suggestions generally emphasise more deliberate decentralisation of management practices, although they also indicate the necessity of partial central planning and control. Overall, these improvements could proactively reduce the barriers created by the differing perceptions, simultaneously opening avenues for enhanced production planning and control practices that take into account the potential of decentralisation.

From an empirical perspective, the study's setting may be considered as novel, as production crews' (and especially workers') perceptions of PP&C have been studied relatively little. By using a multi-method approach, it was also possible to observe the perceptions objectively and subjectively, allowing triangulation of the findings.

Limitations

A comparative case study consisting of social network analysis (SNA) and interviews was selected as a research method to explore phenomena in-depth and to allow triangulation (Eisenhardt and Graebner 2007). However, as the data collection was based on a free-recall, free-choice survey and semi-structured interviews, the results are susceptible to participant bias. Although achieving a 100% response rate for a survey is not critical to the results (see methodology—data

collection section), surveys still have the possibility for errors even with a high response rate. It should also be noted that a single SNA cannot fully address the dynamic nature of complex systems but only provides a stationary viewpoint of the production context, thus creating limitations vis-à-vis the robustness of the results.

Because the study included a limited number of cases, both in Finland, some restrictions might occur in generalising the results, especially to different cultural and geographical locations. As only one case from each category (centralised/decentralised approach) was examined, each with a limited population of data points, certain limitations may be encountered in generalising the results due to possible specialties of the cases and their implementation strategies. It should also be noted that limitations for conclusively assessing the effect of PP&C approaches on overall production performance and productivity exist, as both projects were ongoing during the data collection period.

Avenues for future research

First, future research should examine how implementing this study's suggested improvement actions could advance construction PP&C in practice. These initiatives could also be combined with the development of prevalent PP&C methods, such as the location-based management system (LBMS) or takt production. Such research could also include further analysis of the structure of micro-level decisions to better combine them with formal PP&C processes. Second, in addition to examining project-level studies, future research could examine how production crews' perspectives could be inspected in a larger perspective, combined with insights into a possible cultural change. This approach would be essential to diminish the epistemological gap between managers and crews in the long term. Third, future research could address how decentralisation and the suggested improvement actions could be facilitated through digital innovation. In particular, an interesting avenue for future research would be to examine how transparency of production status and information flow (which would contribute to better recognising PP&C responsibilities and enabling continuous improvement) could be supported through digitalisation.

Note

1. According to the *Merriam-Webster Dictionary* (n.d.) and Mintzberg (1983), "decentralization" refers to a process whereby the power of decision-making is dispersed from a central authority to lower levels of hierarchy, such as to teams and/or individuals. In construction production management, decentralization could mean distributing the PP&C authority from general contractor project and site managers to production crews, allowing them certain autonomy in decision-making.

Acknowledgments

The authors would like to gratefully thank Eemeli Könkkölä, Kiia Haapasalmi, Riikka Joona, and Tuomas Poukka for the assistance in data collection. We would also like to thank the Editor and the anonymous reviewers for their contribution to the peer review of this work, which allowed us to improve the contribution substantially.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The research in this paper has been conducted and financially supported under Digitalizing Construction Workflows (DiCtion) research project funded by Business Finland and a consortium of six industrial partners, by Functioning Street Projects ("ToKaHa") research project funded by the City of Helsinki, and by Building 2030 consortium under projects "Waste in construction design and production" and "Decentralized planning and control in construction" which were funded by a consortium of 21 industrial partners. We are grateful for all provided financial and technical support.

ORCID

Joonas Lehtovaara http://orcid.org/0000-0002-4761-3811
Olli Seppänen http://orcid.org/0000-0002-2008-5924
Antti Peltokorpi http://orcid.org/0000-0002-7939-6612

References

Baccarini, D., 1996. The concept of project complexity – a review. *International journal of project management*, 14 (4), 201–204.

Baiden, B.K., Price, A.D., and Dainty, A.R., 2006. The extent of team integration within construction projects. *International journal of project management*, 24 (1), 13–23.

Ballard, G., and Tommelein, I., 2016. Current process benchmark for the Last Planner system. *Lean construction journal*, 89, 57–89.

Ballard, H.G., 2000. *The Last Planner system of production control*. Dissertation (PhD). University of Birmingham, UK.

Barber, P., Tomkins, C., and Graves, A., 1999. Decentralised site management – a case study. *International journal of project management*, 17 (2), 113–120.

Ben-Alon, L., Sacks, R., and Grobman, Y. J., 2014. Similarities and differences between humans' and social insects' building processes and building behaviors. *In*: *Construction research congress 2014: construction in a global network*, 19–21 May 2014, Atlanta, GA, USA, 51–60.

Bertelsen, S., 2003. Complexity – construction in a new perspective. *In*: *11th annual conference of the International Group for Lean Construction*, July 2003, Blacksburg, VA, USA, 1–12.

Bertelsen, S., and Koskela, L., 2005. Approaches to managing complexity in project production. *In*: *13th annual conference of the International Group for Lean Construction*, 19–21 July 2005, Sydney, Australia, 65–71.

Bølviken, T., Aslesen, S., and Koskela, L., 2015. What is a good plan? *In*: *23rd annual conference of the International Group for Lean Construction*, 29–31 July 2015, Perth, Australia, 93–102.

Burt, R.S., 2004. Structural holes and good ideas. *American journal of sociology*, 110 (2), 349–399.

Castillo, T., Alarcon, L.F., and Salvatierra, J.L., 2018. Effects of Last Planner system practices on social networks and the performance of construction projects. *Journal of construction engineering and management*, 144 (3), 04017120.

Chinowsky, P., Diekmann, J., and Galotti, V., 2008. Social network model of construction. *Journal of Construction engineering and management*, 134 (10), 804–812.

Chinowsky, P., Diekmann, J., and O'Brien, J., 2010. Project organizations as social networks. *Journal of construction engineering and management*, 136 (4), 452–458.

Coffey, M., 2000. Developing and maintaining employee commitment and involvement in lean construction. *In*: 8th annual conference of the International Group for Lean Construction, 17–19 July 2000, Brighton, UK.

Creswell, J. W., and Clark, V. L. P., 2017. *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.

Desai, A.P., and Abdelhamid, T.S. 2012. Exploring crew behavior during uncertain jobsite conditions. *In*: *20th annual conference of the International Group for Lean Construction*, 18–20 July 2012, San Diego, CA.

Diekman, J., *et al.*, 2004. *Application of lean manufacturing principles to construction*. Boulder, CO: Construction Industry Institute, 191.

Drazin, R., and Van de Ven, A.H., 1985. Alternative forms of fit in contingency theory. *Administrative science quarterly*, 30, 514–539.

Eisenhardt, K.M., and Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. *Academy of management journal*, 50 (1), 25–32.

Evans, C.R., and Dion, K.L., 1991. Group cohesion and performance: a meta-analysis. *Small group research*, 22 (2), 175–186.

Formoso, C.T., and Moura, C.B., 2009. Evaluation of the impact of the Last Planner system on the performance of construction projects. *In*: *17th annual conference of the International Group of Lean Construction*, 15–17 July 2009, Taipei, Taiwan, 153–164.

Frandson, A.G., Seppänen, O., and Tommelein, I.D., 2015. Comparison between location based management and takt time planning. *In*: *23rd annual conference of the International Group for Lean Construction*, 29–31 July 2015, Perth, Australia, 3–12.

Freeman, L.C., 1977. A set of measures of centrality based on betweenness. *Sociometry*, 40, 35–41.

Goldratt, E. M., 1997. *Critical chain*. Great Barrington, MA: North River Press.

Granovetter, M.S., 1973. The strength of weak ties. *American journal of sociology*, 78 (6), 1360–1380.

Grant, A.M., and Ashford, S.J., 2008. The dynamics of proactivity at work. *Research in organizational behavior*, 28, 3–34.

Hansen, M.T., 2002. Knowledge networks: explaining effective knowledge sharing in multiunit companies. *Organization science*, 13 (3), 232–248.

Hatala, J.P., 2006. Social network analysis in human resource development: a new methodology. *Human resource development review*, 5 (1), 45–71.

Hickethier, G., Tommelein, I. D., and Lostuvali, B., 2013. Social network analysis of information flow in an IPD-project design organization. *In*: 21st annual conference of the International Group for Lean Construction, 31 July–2 August 2013, Fortaleza, Brazil.

Hinze, J., and Tracey, A., 1994. The contractor-subcontractor relationship: the subcontractor's view. *Journal of Construction Engineering and Management*, 120 (2), 274–287.

Hollnagel, E., Woods, D. D., and Leveson, N., eds., 2006. *Resilience engineering: concepts and precepts*. Aldershot, UK: Ashgate.

Howell, G., and Ballard, G., 1998. Implementing lean construction: understanding and action. *In*: *6th annual conference of the International Group for Lean Construction*, 13–15 August 1998, Guarujá, Brazil.

Huber, B., and Reiser, P., 2003. The marriage of CPM and lean construction. *In*: *11th annual conference of the International Group for Lean Construction*, Blacksburg, VA, USA, 1.

Humphrey, S.E., Nahrgang, J.D., and Morgeson, F.P., 2007. Integrating motivational, social, and contextual work design features: a meta-analytic summary and theoretical extension of the work design literature. *The journal of applied psychology*, 92 (5), 1332.

Janhonen, M., Lähteenmäki, L., and Alvesalo-Kuusi, A., 2018. Turvallisuuden johtamisen kipupisteet yhteisillä työpaikoilla [Barriers for effective safety management in shared workplaces]. *Työelämän Tutkimus*, 16 (3), 169–184.

Johansen, E., and Wilson, B., 2006. Investigating first planning in construction. *Construction management and economics*, 24 (12), 1305–1314.

Johnston, R.B., and Brennan, M., 1996. Planning or organizing: the implications of theories of activity for management of operations. *Omega*, 24 (4), 367–384.

Kaarbo, J., and Beasley, R.K., 1999. A practical guide to the comparative case study method in political psychology. *Political psychology*, 20 (2), 369–391.

Kärkkäinen, R., *et al.*, 2019. Situation picture through construction information management. *In*: *10th Nordic conference on construction economics and organization* (Emerald Reach Proceedings series, vol. 2). Tallinn, Estonia: Emerald, 155–161.

Kelley Jr J.E., and Walker, M.R., 1959. Critical-path planning and scheduling. *In*: *Eastern joint IRE-AIEE-ACM computer conference*, 160–173. New York, NY: Association for Computing Machinery.

Koskela, L., 2000. *An exploration towards a production theory and its application to construction*. Espoo: VTT Technical Research Centre of Finland.

Koskela, L., *et al.*, 2019. Epistemological explanation of lean construction. *Journal of Construction Engineering and Management*, 145 (2), 04018131.

Koskela, L., and Howell, G., 2002. The theory of project management: explanation to novel methods. *In: 10th annual conference of the International Group for Lean Construction*, 6–8 August 2002, Gramado, Brazil, 1–11.

Laine, E., Alhava O., Peltokorpi A., and Seppänen O., 2017. Platform ecosystems: unlocking the subcontractors' business model opportunities. *In:25th annual conference of the International Group for Lean Construction*, 9–12 July 2017, Heraklion, Greece, 177–184.

Laloux, F., 2014. *Reinventing organizations: a guide to creating organizations inspired by the next stage in human consciousness*. Brussels, Belgium: Nelson Parker.

Lanaj, K., *et al.*, 2013. The double-edged sword of decentralized planning in multiteam systems. *Academy of MANAGEMENT JOURNAL*, 56 (3), 735–757.

Laumann, E.O., Marsden, P.V., and Prensky, D., 1989. The boundary specification problem in network analysis. *Research methods in social network analysis*, 61, 87.

Leavitt, H. J., 2005. *Top town: why hierarchies are here to stay and how to manage them more effectively*. Boston, MA: Harvard Business School Press.

Lee, C.Y., *et al.*, 2018. Critical review of social network analysis applications in complex project management. *Journal of management in engineering*, 34 (2), 04017061.

Liker, J. K., 2005. *The Toyota way*. New York, NY: McGraw-Hill.

Loosemore, M., 1999. Responsibility, power and construction conflict. *Construction Management and Economics*, 17 (6), 699–709.

Loosemore, M., 2014. Improving construction productivity: a subcontractor's perspective. *Engineering, construction and architectural management*, 21 (3), 245–260.

Lumsden, P., 1968. *The line-of-balance method*. Tarrytown, NY: Pergamon.

Magpili, N.C., and Pazos, P., 2018. Self-managing team performance: a systematic review of multilevel input factors. *Small group research*, 49 (1), 3–33.

Manu, E., *et al.*, 2015. Trust influencing factors in main contractor and subcontractor relationships during projects. *International journal of project management*, 33 (7), 1495–1508.

Marquet, L. D., 2012. *Turn the ship around! A true story of turning followers into leaders*. New York, NY: Penguin.

Martin, T., 2019. *Self-managed teams: success factors that managers should consider when establishing and sustaining self-managed teams within organizations*. Dissertation (PhD). University of Maryland University College, MD, USA.

McChrystal, G. S., *et al.*, 2015. *Team of teams: new rules of engagement for a complex world*. New York, NY: Penguin.

Mead, S.P., 2001. Using social network analysis to visualize project teams. *Project Management Journal*, 32 (4), 32–38.

Merriam-Webster Dictionary, n.d. Definition of decentralization. Available from: https://www.merriam-webster.com/dictionary/decentralization [Accessed 27 August 2020].

Miles, M. B., and Huberman, A. M., 1994. *Qualitative data analysis: an expanded sourcebook*. Thousand Oaks, CA: Sage.

Miller, C.J., Packham, G.A., and Thomas, B.C., 2002. Harmonization between main contractors and subcontractors: a prerequisite for lean construction? *Journal of construction research*, 3 (01), 67–82.

Mintzberg, H., 1983. *Structures in fives: designing effective organizations*. Englewood Cliffs, NJ: Prentice Hall.

Mintzberg, H., Raisinghani, D., and Theoret, A., 1976. The structure of "unstructured" decision processes. *Administrative science quarterly*, 21 (2), 246–275.

Morris, P. W., 1994. *The management of projects*. London, UK: T. Telford.

Nardi, P., 2006. *Doing survey research: a guide to quantitative methods*. Pearson/Allyn & Bacon: Boston, MA.

Owen, R., Koskela, L., Henrich, G., and Codinhoto, R., 2006. Is agile project management applicable to construction? *In: 14th annual conference of the International Group for Lean Construction*, Santiago, Chile, 51–66.

Pikas, E., Sacks, R., and Priven, V., 2012. Go or no-go decisions at the construction workface: uncertainty, perceptions of readiness, making ready and making-do. *In: 20th annual conference of the International Group for Lean Construction*, 18–20 July 2012, San Diego, CA, USA.

Poleacovschi, C., Javernick-Will, A., and Tong, T., 2017. The link between knowledge sharing connections and employee time savings: a social network analysis. *Construction Management and Economics*, 35 (8–9), 455–467.

Pollack, J., 2007. The changing paradigms of project management. *International journal of project management*, 25 (3), 266–274.

Priven, V., and Sacks, R., 2015. Effects of the Last Planner system on social networks among construction trade crews. *Journal of construction engineering and management*, 141 (6), 04015006.

Pryke, S., 2012. *Social network analysis in construction*. Chichester, UK: Wiley-Blackwell.

Pryke, S., *et al.*, 2018. Self-organizing networks in complex infrastructure projects. *Project Management Journal*, 49 (2), 18–41.

Raelin, J. A., 2003. *Creating leaderful organizations: how to bring out leadership in everyone*. San Francisco, CA: Berrett-Koehler.

Richardson, H.A., *et al.*, 2002. Does decentralization make a difference for the organization? An examination of the boundary conditions circumscribing decentralized decision-making and organizational financial performance. *Journal of management*, 28, 217–244.

Sacks, R., and Harel, M., 2006. An economic game theory model of subcontractor resource allocation behaviour. *Construction management and economics*, 24 (8), 869–881.

Salovaara, P., and Bathurst, R., 2018. Power-with leadership practices: an unfinished business. *Leadership*, 14 (2), 179–202.

Saurin, T.A., Rooke, J., and Koskela, L., 2013. A complex systems theory perspective of lean production. *International journal of production research*, 51 (19), 5824–5838.

Sawhney, A., Bashford, H., Walsh, K., and Mulky, A.R., 2003. Construction engineering and project management II: agent-based modeling and simulation in construction. *In: 35th conference on winter simulation: driving innovation*, December 2003, New Orleans, LA, 1541–1547.

Schöttle, A., 2020. What drives our project teams? *In: 28th annual conference of the International Group for Lean Construction*, 6–10 July 2020, Berkeley, CA, 313–324.
Schröpfer, V.L.M., Tah, J., and Kurul, E., 2017. Mapping the knowledge flow in sustainable construction project teams using social network analysis. *Engineering, construction and architectural management*, 24 (2), 229–259.
Scott, J., 2000. *Social network analysis – a handbook*. 2nd ed. London, UK: Sage.
Seawright, J., and Gerring, J., 2008. Case selection techniques in case study research: a menu of qualitative and quantitative options. *Political research quarterly*, 61 (2), 294–308.
Seppänen, O., Ballard, G., and Pesonen, S., 2010. The combination of Last Planner system and location-based management system. *Lean construction journal*, 6 (1), 43–54.
Soliman, M., and Saurin, T.A., 2020. Lean-as-imagined differs from lean-as-done: the influence of complexity. *Production Planning & Control*.
Stinchcombe, A. L., and Heimer, C. A., 1985. *Organization theory and project management: administering uncertainty in Norwegian offshore oil*. Bergen: Norwegian University Press.
Taylor, F. W., 1947. *Scientific management*. New York, NY: Harper & Row.
Teräväinen, V., Junnonen, J.M., and Ali-Loytty, S., 2018. Organizational culture: case of the Finnish construction industry. *Construction economics and building*, 18 (1), 48.
Turner, J.R., and Cochrane, R.A., 1993. Goals-and-methods matrix: coping with projects with ill defined goals and/or methods of achieving them. *International Journal of Project Management*, 11 (2), 93–102.
Vollmann, T. E., Berry, W. L., and Whybark, D. C., 1997. *Manufacturing planning and control for systems*. 4th ed. Homewood, IL: Irwin.
Wasserman, S., and Faust, K., 1994. *Social network analysis: methods and applications*. Cambridge, UK: Cambridge University Press.
Watkins, M., *et al.*, 2009. Using agent-based modeling to study construction labor productivity as an emergent property of individual and crew interactions. *Journal of construction engineering and management*, 135 (7), 657–667.
Wellman, B., and Berkowitz, S. D., 1988. *Social structures: a network approach*. New York, NY: Cambridge University Press.
Winch, G.M., and Kelsey, J., 2005. What do construction project planners do? *International journal of project management*, 23 (2), 141–149.
Winograd, T., 1986. A language/action perspective on the design of cooperative work. *In: Proceedings of the 1986 ACM conference on computer-supported cooperative work*, 203–220. New York, NY: Association for Computing Machinery.
Yammarino, F.J., *et al.*, 2012. Collectivistic leadership approaches: putting the "we" in leadership science and practice. *Industrial and organizational psychology*, 5 (4), 382–402.
Yang, S.B., and Guy, M.E., 2011. The effectiveness of self-managed work teams in government organizations. *Journal of business and psychology*, 26 (4), 531–541.
Yin, R. K., 2014. *Case study research: design and methods*. Thousand Oaks, CA: Sage.
Zábojník, J., 2002. Centralized and decentralized decision-making in organizations. *Journal of labor economics*, 20 (1), 1–22.
Zhang, L., and Ashuri, B., 2018. BIM log mining: discovering social networks. *Automation in construction*, 91, 31–43.

Appendices

Appendix 1: Social network analysis survey form

Introduction

The survey consists of five sections:

i. General information (such as the role in the project and organization)
ii. General communication (information-flow network)
iii. Power structures (decision-making network)
iv. Specific work tasks related to the crews inspected in the study (planning and control networks, including crew/task-specific sub-questions)
v. Open-ended questions about decision-making (employed to broaden and support interview data qualitatively)

In sections i through iv, subjects were asked to identify project participants with whom they communicated, to whom they had given/taken orders, and with whom they had communicated about the planning or control of the specific work task within the last month. The respondents were also asked to rate the frequency of the communication (from 1 to 5; 1 = once or twice per month, 5 = daily) and the mode of communication (email/project bank/phone/face-to-face/in a meeting) with each participant.

i. **General questions**
Which organisation do you work for, and what is your role in the organisation?
What is your role in the project?
ii. **General communication**
With whom have you communicated within the last month concerning the project? Please name all the people and their organisations and roles in the project.
iii. **Power structures**
From whom do you receive information that is critical in planning your own work?
To whom do you provide information that is critical for others' work planning/project management?
iv. **Specific work tasks related to the studied crews**
With whom have you communicated within the last month concerning the planning or control of the specified work task?
[The respondents were asked to answer the question individually for every selected work task.]
v. **Open-ended questions about decision-making**
How often do you make decisions by yourself regarding your own planning of work?
Please provide two or three examples of situations where you make decisions by yourself.

Appendix 2:

Interview form

i) General questions and reflection of SNA results

- What is your role in the project, and which tasks does it include?
- How long have you been working on the project?
- From your point of view, how has the project progressed?
- [Brief reflection of the SNA results]

ii) General communication

- With whom do you mostly communicate about this project?
- What kind of information do you provide and receive?
- What kind of information do you need to excel in your work?
- What kind of information do others need from you?
- What kind of challenges occur in your daily work, and how do you solve them?

iii a) Production planning and control (project/site management)

- What tasks/works are currently in progress?
- How are the plans made? What is the process, and who is involved?
- How are the tasks controlled? At what intervals, and who makes the decisions?
- How do you participate in decision-making?
- Are there instances when you are able to perform autonomously? Please provide examples.
- Do you feel you have the resources to perform in situations that require rapid decision-making?
- Do you feel you are able to get the information you need to make decisions?

iii b) Production planning and control (crew leaders/workers)

- What tasks/steps does your work involve? In what order do you perform your work?
- How are the plans made? What is the process, and who is involved?
- How are the tasks controlled? At what intervals, and who makes the decisions?
- Are you able to participate in decision-making?
- Are there instances when you are able to perform your work autonomously? Please provide examples.
- Do you feel you have the resources to perform in situations that require rapid decision-making?
- Do you feel you are able to get the information you need to make decisions?

iv) Possible improvement actions

- How would you improve the way in which planning and control is carried out?
- How would you improve the communication and organizational structures?
- What are your insights on decentralized/centralized planning and control?