Engineering Innovative Clinical Resource Management by Design: a guided Emergent Search through a Complex Adaptive System of Systems

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Abstract - This competitive healthcare market has made labour planning and allocation vital to the success of today's hospitals. Nurses' real usage is plagued by inefficiencies and cost overruns because even sophisticated automated planning systems for nursing labour cannot account for the dynamic needs of patient care during and between shifts. Typical labour measures increase the situation, as we've discovered. Iterating through many objects with practitioners in situ, we adopt an extended action design science research (eADR) strategy. When it comes to filling important nursing and support tasks in real time, we find that understanding the behaviours of complex adaptive systems is vital. We utilise this information to identify management procedures that clash and obstruct the efficient operation of feedback loops for system balance. For real-time nurse labour planning and allocation, we used an electronic ADR strategy that included co-design, co-evaluation, and co-implementation of new structures, roles, and responsibilities. Patient outcomes may be greatly improved by using this novel artefact, which takes use of the dynamic actions of the actors.

Index Terms—Complex adaptive systems (CAS), design science research, dynamic labor management, health care.

I. Introduction

After being introduced by Sein et al. in their foundational study, ADR has developed. When applied to "wicked" sociotechnical issues in operations management, Mullarkey and Hevner [12] have developed the extended Action Design Research (eADR) technique, which is capable of accommodating the long-term artefact construction and assessment constraints. Existing methods generally fail to cope with dynamic decisions impacted by highly stochastic flows and human behaviours in complicated corporate contexts. The average hospital uses labour planning and allocation cycle (LPAC) technologies at every organisational level to help supervisors manage their workforce more effectively. While automated labor-management forecasting LPACs can often maximise several coefficients in a spreadsheet or algorithm, they fail to adapt well to real-time changes in the system's variables. For example. Intervening with practitioners to diagnose and build alternative solutions in these complex system contexts is made easier using eADR, which takes a systematic approach.

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Researchers and practitioners may work together to co-create and co-evaluate different sociotechnical solutions to this issue domain using ADR's "action" and "iterative" components for creating and assessing labour management artefacts. Systems theory and the practise of electronic evidence-based decision-making (eADR) may assist labor-management optimization of numerous connected factors to build a dynamic response to changes in demand, acuity, and flow of skilled nursing resources. McDaniel et al. [1] classify hospitals as CASs, or complex adaptive systems. Researchers are hindered by the inherent difficulty of labour management in CAS contexts. Focusing on only one piece of the puzzle, such labour scheduling, might overlook the intricacy of activities that interact with each other in a system. The complexity of hospital systems is heightened by the fact that they are nonlinear, lack unidirectional causality, and lack predictability. Patient and skilled nursing resources are left to "blindly stumble through the health care system," as Gulick puts it [2]. Because of this, hospital managers are unable to observe how patient care-driven events and acuities influence choices that transfer patients across departments and into and out of hospital beds because of the lack of labour planning and allocation systems.

Labor forecasting models that are typically linear in nature have limits when it comes to simulating CAS. Quantitative research based on regression, Bayesian nets, complex differential calculus, or partial differential equations provide restricted models effective for describing CAS component behaviour.... "The approach of reduction—study the pieces, then sum up the parts' actions to derive the behaviour of the whole—does not work" [3]. It was necessary to use a technique that allowed academics and practitioners to work together to undertake an emergent sequence of interventions to examine the system as a whole and a system of systems in an iterative manner. We needed a new method that combined eADR with CAS paradigms while also using a "systems of systems" perspective to address the system's intrinsic complexity as well as the need to design for highly unexpected dynamic interactions among the players inside and across systems.

For departmental labour forecasting, scheduling, and staffing, we find that the system of systems method is critical in evaluating the intradependent and interdependent dynamics involved. As a result of this procedure, the research went beyond artefact diagnosis and design to artefact evolution [4]. It was our goal to create a generalizable artefact that could be used to help hospitals better manage their nurse labour and enhance nursing usage efficiency while still maintaining high standards of patient care.

For example, we used the eADR process model to construct an LPAC for skilled nursing in a normal US hospital to increase labour cost-effectiveness, nurse satisfaction, and patient outcomes in a typical hospital.

In our diagnostic stage, we failed to account for internal and external subsystem dynamic elements since we were focused on improving departmental scheduling and staffing activities. Factors left unaddressed were human judgement in real-time, communication between and inside systems, leadership interaction and response to changing patient demand.

Multi-iterative subsystem and macrosystem artefact abstractions were used to build and assess the final nurse labor-management model. Final results were an unique artefact defining the conceptual model of a supporting information system to assist the interactions essential for labor-management across the CAS of systems of a typical U.S. general hospital, which was deployed in two distinct hospital contexts.

II. Literature Review

Trans jour.docx may be opened by clicking on View|Page Layout in the menu bar (since our research of relevant preceding literature showed three significant gaps in knowledge surrounding labour management in CASs). It should be noted that in the past, labour management functions like forecasting, scheduling, and hiring have often been examined in isolation.

These studies focus only on solving one issue at a time, without taking into account the functional interdependencies. Studies tend to focus on single-function settings or service lines rather than a hospital's whole network of service lines. Finally, the labour forecasting issue is approached from an algorithmic automation viewpoint in the literature. These solutions are aimed at eliminating the requirement for human contact and judgement by removing people from the processes.

III. Diagnosis—The Hospital Labor-Management Challenge

Almost 60 percent of all hospital costs are accounted for by labour in 2018 [6]. Overtime and contract work in the field of nursing have risen as a result of this trend. According to Shoemaker and Schuhmann's estimates [7] and Wheatley's estimates [8], contract labour accounted for 3 percent of total personnel costs by 2005, while overtime accounted for 4.5 percent of total work hours. In the typical U.S. hospital, contract labour and overtime hours at these projected percentages cost almost $1 million annually, according to KPMG's 2011 U.S. Hospital Nursing Labor Costs Study.

In order to control labour expenses, hospital managers in general and nursing leaders in particular are being pushed to discover ways to flatten the curves of each of these increasing tendencies. Hospital systems may save a large amount of money by using contract workers and avoiding overtime. With an awareness of how hospitals are organised, it is possible to plan and use human resources more effectively.

It is common for hospitals to have separate LPACs for each specialty department (e.g., the medical department, critical care department, etc.). This is followed by a system called a "service line," which is made up of a number of closely related departments that provide a variety of services under the same general heading. Functional parts of the hospital, such as inpatient, outpatient and ancillary, are made up of service lines. There must be regular communication between each level of the hospital system and subordinate systems in order to ensure proper nurse labour planning. On a daily basis and on a weekly/monthly basis, however, the reality of nursing labour coverage often remains an isolated or semi-isolated difficulty for the lowest level of systems inside this system, which happens to be a department. At this level, the nurse leader must concentrate on "particular assignment" for a given day and time. For this reason, these executives are held responsible for ensuring that each resident patient has appropriate personnel as needed by patient care regulations. With minimal control over patient flow or acuity on any given shift, nursing supervision must plan 1-2 weeks in advance using either automated or manual LPACs and respond to actual patient flows—often with less than 30 minutes notice—in real-time each shift.

Sociotechnical labour planning methods often result in siloed and inefficient subsystems that facilitate suboptimizing behaviour that tries to improve patient care in siloed departments without optimising the service line, functional area or the hospital-wide nursing labour allocation. Through their emphasis on optimising the department's expected nursing and support labour, present LPACs tend to aggravate labour supply disparities.

Cross-utilization of nursing personnel may be hampered by a lack of appropriate nursing education, experience, and certification. Even so, there are ways in which workers may be shared across departments within a service line and between service lines. Cross-utilization may benefit the similar service lines connecting each site for bigger firms with many locations in close geographic vicinity.

A critical part of the diagnosis process in eADR is including practitioners in the discovery and definition of the issue, as well as possible solutions. A thorough DiagnosisADR stage was performed in this research activity, leading researchers and practitioners alike to recognise that the existing LPAC approach contributes to an overall labour imbalance, leading to suboptimization of labour cost-performance due to a lack of fluid communication and labour flow between and among departments. The requirement to assure patient bed coverage due to rapid changes in patient flow or acuity was regularly cited by departmental nursing directors as a reason for staffing or even overstaffing with expensive nurse labour alternatives. As a self-defense strategy, this activity is motivated by the desire to ensure that patients get the best possible treatment. As a consequence, a straightforward (albeit expensive) solution to a complicated issue is achieved. Research shows that nursing supervisors often rely on reliable, repeatable sources when they are uncertain about their capacity to adequately care for a patient. There were a number of ways to generate overtime in the hospital systems analysed, including requesting departmental nurses to work extra hours (generating overtime) or contacting contracted (standby) nursing companies. The issue is made worse by the fact that one department may face increased (and sometimes unbudgeted) costs at the same time as other departments are letting go of competent employees. When you include in the difficulty of physically and emotionally transporting nurses across a hospital campus, the situation gets much worse.

This issue domain is experienced at a distinct degree of abstraction by each system inside the system. Because of this, senior system administrators often find it difficult to explain or justify the cost of nursing labour. It's very hard to pinpoint the precise shift in census and acuity that generated the aggregated nurse labour cost overages without comprehending each departmental supervisor's actions for each shift.

As a consequence of the nurse supervisors' requests for explanations and justifications, hospital administrators and LPAC developers engage in labor-management conduct that pits "us" against "them." Even if each leader "tried to do their best for patients," the suboptimal exploitation of this extremely vital resource becomes the sticky wicked dilemma in quest of a solution. It's also possible that the inability to dynamically "spread" nurse labour between departments might lead to fierce rivalry inside and across service lines, lowering overall labour management performance and, ultimately, harming patient care and increasing total costs.

There is a critical need for a labour management solution that can bridge the dependency and interdependence on this valuable human resource between different layers in an organization's systems and focus on developing naturally balanced feedback loops and communication flows to optimise desired behaviours among those systems.

IV. Design—Shifting From Lpac To Dynamic Labor Management

The LPAC is a relatively static method of managing (communicating and organising) nurse work in a patient-care system based on patient flow and acuity within a certain department. When seen across numerous departments, service lines, and functional areas of a typical hospital, the system's complexity becomes visible and geometrically more complex. The complexities of a CAS study necessitated a research team's positioning where the problem exists—at both the strategic and operational layers—interacting with key nursing hospital and departmental leadership representatives tasked with addressing this "mission-critical" skilled nursing labour availability. The study technique has to go beyond basic anecdotal observations to explain why scheduled nurse labour seldom satisfied specific departments' real-time demand demands. Rather, we wanted to assess how and why each LPAC process instantiation may influence labour planning and allocation tasks across different system levels. We needed to break down current procedures to their fundamental components and then rebuild them around the hospital's multileveled complicated systems.

Recognizing that I.T. systems and automated tasks were not the fundamental causes of the complicated issue, we moved on to the design stage of eADR, which is based on action research [12]. Our objective was to use many cycles of artefact coevaluation with practitioners in situ to design, develop, assess, and enhance a novel artifact—the Dynamic Labor Planning and Allocation Management model (D-LPAM). The treatments focused on "dynamic" real-time patient flows and co-created and co-evaluated artefacts within the different eADR phases. These initiatives identified a future-state Dynamic LPAM and developed it, maximising the balance between labour and patient outcomes at several system levels. Rather than optimising the individual components of workload forecasting, scheduling, and allocation across individual departments, this study took a novel approach by looking at all three components within the complex levels of hospital subsystems, paying special attention to the multiple layers and interactions involved. These relationships were studied within the natural boundaries and restrictions of organisational structures, knowledge creation/sharing activities, and interaction participant dynamics (human–human, human–machine, and machine–machine).

The Design stage of our study was led by the following research questions.

1) How can a system of systems approach to labour management promote better overall system results by improving the balance between nursing work, nurse satisfaction, and patient outcomes?
2) How might an eADR technique aid in the analysis and resolution of a "wicked" issue in a CAS setting?

V. THEORETICAL FRAMEWORKS GUIDING ARTIFACT DEVELOPMENT

For more than 70 years, researchers have recognised the benefit of understanding organisations as dynamic systems that build a whole that is more than the sum of its parts. This perspective has

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been utilised in healthcare to examine the influence of patient throughput on care quality. However, there is little prior research that applies this viewpoint to hospital labour management.

Researchers have lately used the SEIPS (Systems Engineering Initiative for Patient Safety) to assess the quality of health services and patient care. The SEIPS model examines the work system or structure, as well as the process and consequences. The model suggests that these entities have interconnections and interdependencies because the work system influences how work is done in a process, which influences results. Our study takes a similar approach, examining labour management functions via the interplay of people and technology in order to rethink work systems and improve system outcomes.

Individual system components cannot be readily understood or assessed in a CAS. In these sorts of systems, there is an inherent difficult to forecast system outcomes using subsystem result prediction. The adage "the whole is greater than the sum of its parts" does not apply here. While previous academics have used CAS thinking to public health systems, general health care organisations, or multi-hospital systems, there is limited study on the use of CAS principles in hospital management.

Twenty years ago, Anderson and McDaniel examined the implications of CAS thinking for health-care organisations. We observe little evidence of adopting these principles and insights in today's health-care organisations, which is consistent with the practitioner—research gap. Five fundamental qualities that identify a CAS, according to McDaniel et al. "1) learning agents, 2) nonlinear interdependencies, 3) self-organization, 4) emergence, and 5) coevolution," according to the authors. These characteristics were applied to hospital labor-management activities in order to better understand the nature of the environment and provide a framework for directing the creation of the artifact.

Hospitals are made up of many layers of subsystems that work together to deliver patient care services while maintaining a delicate and artistic balance between labour supply and demand as defined by patient requirements. Patients' transit across the different subsystems of care leads departments to be interconnected in a variety of ways. From a labour viewpoint, however, these interdependencies reveal no instantiations in formal organizational linkages, enabling us to consider departmental LPACs as independent, distinct agents. Tarpey and Mullarkey present a more extensive definition of hospitals as a "system of systems."

VI. ELABORATED ADR ENTRY POINT

Depending on the issue situation, the extended ADR process model provides for different entrance points. The current practitioner-researcher collaboration had previously completed a three-stage ADR process, which included diagnosing, designing, and implementing an initial D-LPAM model artifact in three different departments at one hospital. The D-LPAM paradigm, which was engrained in STS, offered a template for centralizing labor-management operations under specialized resources committed to executing and monitoring performance 24 hours a day, seven days a week, 365 days a year. The model studied and recorded the data and information contact points (both system and human) that are required for effective labour analysis and choices in order to maximize D-LPAM results. We proposed that segregated procedures and mindsets caused businesses to lose out on numerous possibilities owing to inaccessible information trapped in informal and formal interactions. Due to the project's intricacy, execution, and societal acceptability issues, it was purposefully confined to a "prototype" notion. While the model showed enhanced performance at the departmental level, it did not take into account CAS interactions and complexity.

By entering the expanded ADR process model in the evolution phase, this instance of our study expands on previous research. The evolution phase, according to Mullarkey and Hevner, is when the artefact develops through time, reacting to changes in the environment. Our aim as we entered the Evolution phase was to develop our artefact to meet the more complicated and unpredictable CAS hospital setting, as well as to evolve our model with the flexibility of self-adapting skills to survive in a constantly changing CAS environment (see Fig. 1).

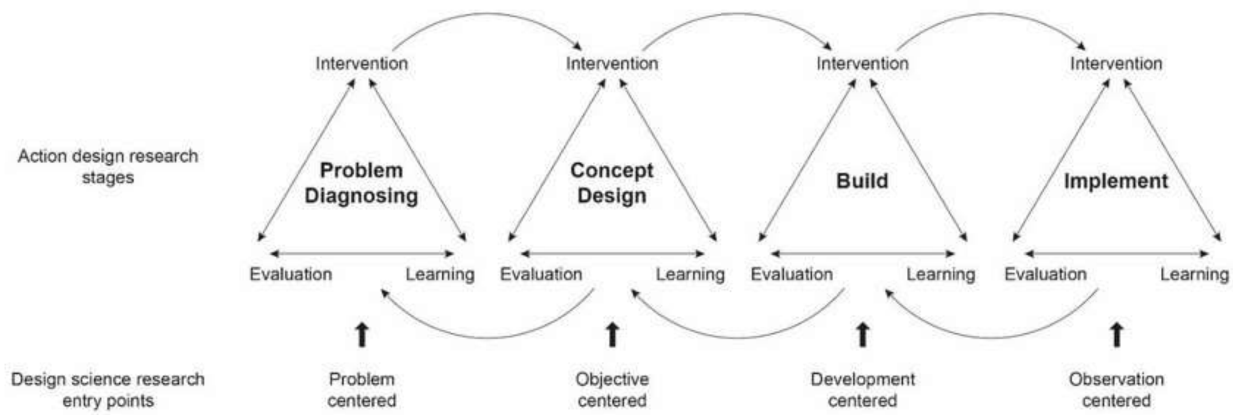

Fig. 1 ADR entry points that have been elaborated

To stage gate the deployment of departments (service lines) and build up the hospital's subsystems, our project used a four-phase method. Each stage-gate phase represented an iteration of the enhanced ADR cycle, which included planning, artefact creation/revision, assessment, reflection, and learning. We proceeded to grow our artefact as we moved through each of these cycle phases, increasing its potential.

VII. EVOLVING THE ARTIFACT

The expanded ADR's Evolution phase is observation-based. The practitioner–researcher collaboration kicked off the re-search with a workshop to explore and recast the prior research challenge using a CAS lens that focused on system outcomes. From increasing departmental LPAC results to enhancing D-LPAM system outcomes across the subsystems, the initial department-centric challenge developed. The team came to an agreement on the concept of hospital subsystem layers and the goal of improving overall system results. Because system optimization was expected to require a future tradeoff with individual component performance as evaluated by current metrics, agreement on this goal was important to going further. The team realised that this compromise would most likely result in unhappiness and perhaps pushback from subsystem leaders.

The next step was to re-engage the research team by observing the already instantiated D- LPAM artefact in each of the three hospital departments. The team conducted a detailed examination of current role, task, data, system, and communication channel structures to determine feasibility to support a systems approach to the D-LPAM functions, demonstrating the close match of the eADR research methodology to our problem's solution demands. Observation alone would not have revealed the crucial social-technical factors needed to fully assess the present D-LPAM model. We can only learn about the complicated and, in many cases, secret information flows and exchanges that support job activities inside a CAS if we participate in the research team process. The present model was assessed to see if it could strike a compromise between keeping solution skills for the lowest D-LPAM system (department) and the model's capacity to address higher order issues associated with higher subsystems.

We moved on to the D-LPAM model refinement at this time. Our goal was to either confirm or enhance current data, systems, and human interactions in order to facilitate system-level D-LPAM function execution. To put it another way, at system levels where resources may interflow, maximizes labor-patient balances. In developing our artefacts, we focused on both technological and human integration aspects. When understanding integration is strong, Glover et al. found that integrating social and technical components is favorably linked with care quality. We hypothesized that this favorable link extends to system-level labor-management results, since labour is an important factor in providing high-quality patient care. To record the integration, our artifact creation activities focused on understanding both the formal and informal integration processes of technological and human components. With this information, we created a model to show role players where vital knowledge may be found, whether it's in I.T. systems, non-system data, or knowledge held by other participants. Our hypothesis was that role participants commonly made choices without having access to all relevant system-impact data, resulting in the majority of departmental under-optimization.

VIII. PERFORMANCE MEASUREMENT METHODOLOGY

In a previous expanded ADR project, determining a technique for assessing performance outcomes across multiple subsystem levels was a difficult task. To develop measurement artefacts helpful in monitoring and analyzing results, this study assessed numerous possible performance measures for each of the D-LPAM tasks of workload forecasting, scheduling, and staffing. Over numerous rounds of the eADR cycle, the same practitioner–researcher collaboration cocreated and evaluated the measures. The team used the process to create and evaluate metric artefacts that matched four key criteria: adoption, time-series comparisons, organisational level comparisons, and system viewpoint (see Table 1 for definitions of these criteria).

TABLE 1 MEDICAL-SURGICAL DEPARTMENT STAFFING MATRIX EXAMPLE

Patient Min	Patient Max	Charge RN	RN	Nurse Tech	Unit Clerk	Labor Bin
0	7	1	2	0	0	1
8	9	1	2	1	0	2
10	15	1	3	1	0	3

For practitioner utility, the first requirement was crucial. To be helpful as a possible transformational artefact, every performance assessment must have practitioner credibility. As a result, this acceptance criterion demanded that each measure be simple to comprehend and give relevant data to rapidly and properly diagnose the condition of any of the D-LPAM model's component phases in order to elicit either a confirming or a corrective action (adoption requirement). The second criteria was that each measure allow for data comparisons across several data series and time ranges or time series in order to compare departments and subsystems before and after deployment (time series comparisons requirement). To assess model performance across various organisational structures, the third criteria required each measure to permit comparisons across numerous data series from different hospital departments and other hospitals (organisational structure comparisons requirement). The fourth criteria were that the metric allow for "rolling-up" of departments into subsystem or group metrics for evaluation (system perspective requirement). This was a criterion for evaluating subsystem performance.

The results of the three D-LPAM functions were used to provide evaluations for both the pre- and post-implementation stages. The quality of schedules was assessed using the schedule metrics proposed by Tarpey and Nelson to assess schedule quality on four dimensions: commitments, completeness, healthiness, and preferences. The workload forecasting and staffing indicators were a little more challenging. The emphasis of these measures had to be on how well the workload forecasting or staffing function supplied labour coverage for the patients' demands as specified by the department's staffing plan. This approach included a thorough evaluation that went beyond the anticipated number of patients and the number of personnel in the department.

IX. RESULTS

When looking at the D-LPAM model from a systems perspective, we don't necessarily anticipate intermediate metrics to increase if the goal is to reduce departmental suboptimization. Instead, as the crucial D-LPAM model end performance evaluation, we emphasise on having the optimum quantity of workers at the bedside across all departments. Overscheduling nurses in one department is permissible in a service line perspective if we know that another department in the same service line is short on nurse coverage during the same time period. The engagement of practitioner leadership was crucial in implementing this plan to guarantee that surplus employees in one unit is capable (certified and competent) of working in the equivalent department when supply is inadequate.

Pre-implementation result measurements for specific departments were compared to post-implementation outcome metrics for the corresponding departments, and higher subsystems were discovered. The new D-LPAM model outputs were assessed using this technique, which gave paired observations for comparison. Three months before implementation was the preimplementation result measurement time horizon, and three months after implementation was the postimplementation outcome measurement time range.

Under the revised model, the workload prediction F-SbMAE values worsened in three departments. During the postimplementation period, one department (Hospital A-Medical/Surgical Department #3) saw considerable volume fluctuation, making forecasting much more difficult. The number of patients in the facility fluctuated between five and fifteen on a regular basis, with no discernible pattern. The practitioner–researcher collaboration found it promising that resources noticed the patient volume variability early via enhanced communication and touchpoints, resulting in two good outcomes. To begin, the teams swiftly adjusted to the volume changes by modifying employees in real time as well as in future schedules. Second, without urging from high leadership, talks about the patient placement approach to decrease variability started. These findings backed up our D-LPAM model's potential to improve cross-functional communication and early detection of exception scenarios.

Different scenarios occurred in the other two departments (Hospital B-Medical/Surgical Department #4 and Hospital B-Medical/Surgical Department #10). Due to a low number of patients, these departments had to close on a regular basis during the post-implementation period. When patient numbers drop, hospitals often cluster patients into available departments to increase efficiency and save overhead expenses. The D-LPAM model encouraged interactions that identified closures and led to leadership talks about techniques to predict closures. The D-LPAM artefacts were altered to meet low volume closure circumstances, demonstrating their potential to self-evolve. This skill was highlighted by the practitioner leadership team as a sign of the D-LPAM model's long-term viability.

A. Scheduling

The D-LPAM model's next level is labour scheduling. Based on the workload prediction and the staffing matrix, resources try to allocate personnel to preset schedule slots in this function. To examine the quality of the labour schedule, six schedule quality measures were used to assess scheduling performance. The following were among the metrics:

1) Completeness—this metric assesses the efficiency of a timetable in meeting workload demands.

2) Professional Completeness—similar to Completeness, but geared for nursing personnel.

3) Support Completeness—similar to Completeness, but geared at non-nursing support personnel.

4) Commitments—this metric represents the percentage of employees that are planned for full allocation or commitment.

5) Healthiness—measures the percentage of employees who work on a healthy schedule (absence of unhealthy shift patterns).

6) Choices Respected—represents the percentage of employee scheduling preferences that are respected.

Typically, departments prioritise their calendars throughout the scheduling process. The service line subsystem is prioritised in the new D-LPAM approach. The goal is to schedule workers across the service line to satisfy requirements identified at the service line level, with the assumption that staff will migrate across departments with similar demands, subject to different hard and soft limitations. The emphasis today is on schedule quality throughout the service line subsystem, balancing across the subsystem to correct for overages and underages in each department, decreasing scheduling suboptimization, and removing the siloed approach. As we

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concentrate on service line coverage, this new emphasis may lead individual department schedule quality ratings to decline.

There were two parts to our scheduling performance study. Pre- and post-implementation, we compared schedule quality ratings at the departmental level and at the service line subsystem level. We expected that the new D-LPAM model's subsystem scheduling priority would cause schedule quality scores at the department level to deteriorate. Individual department score data for each schedule quality criteria may be found in Table 2.

Table 2 Data Quality Results, Descriptive Statistics for Data Completeness Checks.

	Baseline Refresh				Final Refresh			
	DataMarts*	Min	Median	Max	DataMarts*	Min	Median	Max
Data Check 3.01 Diagnosis records per encounter, N								
Ambulatory encounters	60	0.00	2.17	100.16	64	0.77	2.08	6.14
Inpatient encounters	59	0.00	6.92	46.99	59	1.11	9.62	45.97
Emergency Department encounters	53	0.00	3.26	12.54	58	0.00	3.37	12.62
ED to inpatient encounters	14	0.55	14.19	51.24	20	2.84	15.47	77.41
Data Check 3.02 Procedure records per encounter, N								
Ambulatory encounters	59	0.00	1.07	166.10	64	0.00	1.56	8.32
Inpatient encounters	58	0.00	4.42	173.90	59	0.00	10.14	173.18
Emergency Department encounters	52	0.00	1.36	16.66	58	0.00	3.47	16.66
ED to inpatient encounters	14	0.41	20.77	158.62	20	0.45	41.54	159.05
Data Checks 3.03 and 3.04 Missing or unknown values, % of records								
Birth date	64	0.00	0.00	82.51	64	0.00	0.00	8.51
Sex	64	0.00	0.04	6.00	64	0.00	0.04	5.82
Diagnosis type	64	0.00	0.00	17.85	64	0.00	0.00	1.82
Procedure type	63	0.00	0.00	100.00	64	0.00	0.00	100.00
Vital source	62	0.00	0.00	100.00	62	0.00	0.00	100.00
Race	64	0.67	27.20	86.43	64	0.69	21.94	86.09
Discharge disposition, institutional encounters	59	0.00	24.41	100.00	59	0.00	3.48	100.00
Principal diagnoses, institutional encounters	58	0.00	0.00	100.00	59	0.00	0.00	100.00

*The number of DataMarts varies by measure because of the data available in each DataMart. The number of DataMarts for a given measure may vary between the baseline and final refresh if network partners added, removed, or reclassified the data in the DataMart. ED = emergency department.

X. DISCUSSION

In a CAS setting, hospital labour planning and allocation procedures coexist across systems at multiple levels of abstraction. The CAS environment becomes dynamically complicated when demand is required to be dynamic and driven by the uncontrolled behaviour of actors' attributes - patient acuity and patient flow. Through practitioners' participation in the eADR cycle's repeated iterations, our study improved the CAS capacity of a D-LPAM model artefact.

As previously stated, there are several consequences for hospital operations. The ability to employ and share labour throughout the hospital CAS is constrained by varying patient care demands and labour specialisation. The artefact design element took into account this restriction on flexibility, implying that a higher degree of design ingenuity would be necessary to leverage supporting staff mobility while restricting nursing staff movement. We also recognise the social factors of employee willingness and fit, which may impose additional constraints but need more investigation. Our study used these limits as a strength built into the artefact, allowing us to quickly rebalance labour to fulfil strict time requirements while staying within labour mobility constraints.

We gained a broader knowledge and improved our capacity to work through the following modification, assessment, reflection, and learning stages of each of the eADR iterations by progressing through the eADR iterations in situ with the practitioners. We also benefitted from shared reference points and experiences, which reduced the risk of data misunderstanding or distortion that may have occurred if we had relied simply on observations made outside the processes. In this article, we utilize the eADR approach to support McDaniel, Lanham, and Anderson's argument that research designs in CAS contexts must "learn about what is in front of us rather than being restricted by predetermined study ideas."

XI. CONTRIBUTIONS

Our study used eADR in a unique and original way to solve a long-standing, "wicked" operations management challenge in hospitals: skilled nurse labour planning and allocation. The eADR technique was effectively extended to design, create, and test a new sociotechnical labour planning and allocation management system artefact. With an examination of the abstracted artefact at several system levels in the hospital, the unique design resulted in enhanced labour effectiveness. The D-LPAM artefact that resulted was shown to dramatically enhance the dynamic balance of staff allocation based on changing patient needs in real time, eventually replacing long-standing but severely suboptimized resource allocation planning methods. Even if individual subordinate and peer-level systems are sometimes prone to individually punishing inefficiency, the study showed that improved efficiency for the system as a whole is attainable. A "system of systems" approach based on patient demand flows provided the multilayered system integrations required for a successful transition, in which centralised role participants used information flows and interactions to optimize higher system D-LPAM model performance to better balance labour allocation, nurse satisfaction, and patient care across all D-LPAM model components.

We show that in organizations managing skilled nursing labour in a "system of systems" setting, the sociotechnical systems dealing with labour, patients, and scheduling are complicated. In these circumstances, conflicting subsystem efficiencies hamper the construction of a better future. Iteratively creating and analyzing an innovative system design via a more deeper review of labour planning and allocation procedures within an integrated system of systems proven beneficial with a practise inspired, theory rooted participation of researchers and practitioners. From the sub- (departmental) to the mid- (service line) to the macro- (functional) level of analysis, the study highlighted the importance of assessing the emerging artefact at each level of abstraction. The artefact must be evaluated at each system level. The danger is that artefact assessment will only be done at one of the system levels, which is fatal in a system of systems environment. The end-state objective of our study was a comprehensive examination and knowledge of system-level performance.

As each of the intermediary processes and interactions was abstracted and assessed for value and contribution to performance, the system architecture improved. We discovered that evaluations were not only necessary for the final product, but also for each iterative abstraction of the artefact at each subsystem layer to measure performance on intermediate and ultimate outcomes for labour efficiency, nurse satisfaction, and levels of requisite patient care. We also discovered that artefact abstraction and assessment have to take place throughout time, from planning to forecasting, scheduling, and staffing. Using the design-centric eADR technique, we provide this bidirectional artefact abstraction and evaluation—vertically across the hospital hierarchy and laterally across the timeframe for labour allocation procedures.

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