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Muddling through in the intensive care unit – A FRAM analysis of intravenous infusion management

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Abstract

Muddling through can be understood in terms of the trade-offs healthcare workers make in response to tensions and contradictions in their everyday work. This gives rise to the performance variability observed in work-as-done. This chapter describes the application of the Functional Resonance Analysis Method (FRAM) to study performance variability, and thus how trade-offs are made, in the intensive care unit. The case study used is the management of intravenous infusions. Using FRAM, several instances of performance variability were identified and analysed for their impact on other functions. The FRAM analysis can be a useful tool for reflection for those involved in delivering and managing the work, and it can provide guidance for the design of tools and technologies.

Introduction

In previous contributions to this book series on Resilient Health Care (RHC), I explored how healthcare workers make dynamic trade-offs, for example when handing over a patient between an ambulance crew and emergency department staff or when referring a patient from the emergency department to a hospital ward (Sujan et al., 2019, Sujan et al., 2015b). The reason why this focus on making trade-offs is important is that in any health system there are inherent and inevitable tensions and contradictions, which cannot be designed out, but which require resolution within the context of a specific situation, i.e. a dynamic trade-off. The ability to make such trade-offs is, therefore, a mechanism of resilience and an expression of "muddling through with purpose".

The need for trade-offs has been articulated in different ways, for example via a recourse to complexity science suggesting that modern systems are inherently intractable (Braithwaite et al., 2013, Hollnagel, 2014), or via highlighting the mismatch between demand and capacity (Anderson et al., 2016). Personally, I align with the notion of tensions and inner contradictions, as expressed in the writings of Vygotsky, Luria and Leontiev, who founded the cultural-historic Activity Theory (Vygotsky, 1978). Activity Theory uses the concept of inner contradictions of an activity. Contradictions are misfits or misalignments within an activity or between activities. The mismatch between demand and capacity could be regarded as one specific case of a contradiction, but the concept of contradictions is more far reaching and can include other expressions, such as competing priorities or goal conflicts where an activity involves multiple people. Contradictions manifest themselves externally as disturbances or disruptions, i.e. as the undesired effects that we perceive. These undesired effects cannot simply be eliminated without addressing the underlying contradiction.

However, the fundamental point of the application of dialectics within Activity Theory is that contradictions are enabling change and development (Engestrom, 1987). It is the contradictions that lead to innovations, which in turn inevitably create new contradictions. Readers with an inclination for the philosophical will note that this application of dialectics originates with German philosophers Hegel (applied idealistically) and Marx (applied materialistically), but this philosophical discourse is beyond the scope of the chapter.

The above theoretical outline might sound very abstract, but regardless of the theoretical stance one subscribes to, all of these theories suggest that in modern health systems people, and the systems within which they work, need to adapt what they do (work-as-done) rather than just follow rigid work procedures and protocols (work-as-imagined). Hence the need for studying how healthcare workers make trade-offs, so that we can support their ability to make these trade-offs successfully more frequently (Sujan et al., 2015a).

What I found in my previous book chapters is that people make dynamic trade-offs based on their experience and based on what could be regarded a subjective and intuitive risk assessment of the current situation. I illustrated this with the example of the "secret second handover", which describes how paramedics resolve the inherent tensions (or contradiction) between staying with the patient under their care at the hospital until they are satisfied that they have communicated to hospital staff all relevant details, and the urgency of leaving the hospital quickly in order to meet the needs of other patients in the community. Interviews with paramedics revealed that they resolve this tension through a very subjective feeling of "being worried" – when they are worried about their patient, they will wait until they are reassured that they have handed over everything about the patient properly. When they are not worried, they are more inclined to trade-off the other way, and potentially even hand over to another ambulance crew while waiting in a queue outside of the hospital.

Trust (Kramer, 1999) and psychological safety (Edmondson et al., 2004) are further factors that influence how healthcare workers make trade-offs. When referring a patient from the emergency department to hospital wards, the clinicians involved need to negotiate jointly a number of trade-offs, such as reducing overcrowding in the emergency department while ensuring that a full diagnosis is available in order to send the patient to the right ward. How this trade-off is resolved clearly depends on the acuity and condition of the patient, but not just. If there is a level of trust and if people feel safe to take interpersonal risks, then these referral conversations are more likely to be responsive to considerations such as perceived business of the emergency department. If, on the other hand, these factors are missing, then the trade-off is more likely to be resolved according to the (static) protocols, i.e. referrals must have a clear diagnosis. This can lead to behaviours referred to as "selling patients", which can cause frustration and further distrust (Nugus et al., 2017).

My aim in this chapter is to illustrate how the Functional Resonance Analysis Method (FRAM) might be used to study how healthcare workers make trade-offs and how FRAM can help with exploring the impact of these trade-offs on other activities. The FRAM (Hollnagel, 2012) probably does not require any further introduction as it is an increasingly well-known technique, but in the next section I give a very brief overview of its key principles and how it can be applied to study trade-offs. Then, I describe the case of intravenous medication management in the intensive care unit (ICU), where FRAM was applied to study how infusions are ordered and administered. I conclude the chapter with a reflection on lessons learned.

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FRAM

FRAM is one of the most significant and widely used methods developed within the Resilience Engineering paradigm (Patriarca et al., 2020). FRAM moves away from the assumption that accidents are caused by component failures and human errors. Instead, the thinking behind FRAM suggests that failures can result from dysfunctional interactions, where variability spreads in unexpected ways and is reinforced throughout the system. FRAM is increasingly being used as a prospective analysis method for understanding performance variability in everyday work or work-as-done (WAD). FRAM has seen widespread uptake especially within healthcare, where the complexity of everyday clinical work lends itself particularly well to the study with FRAM (Kaya et al., 2019, Pickup et al., 2017, Raben et al., 2018, Schutijser et al., 2019). Considering the diversity of applications and the various extensions and modifications that different authors have proposed, it is hard to speak of "the" FRAM as if it were a neatly laid out algorithm. Arguably, this flexibility that allows the method to be used in different ways and with different emphasis is a strength of FRAM. Nonetheless, a FRAM analysis typically consists of these core steps: (1) identification of functions, (2) description of performance variability, (3) analysis of couplings, and then (4) managing variability.

Performance variability is often an expression of trade-offs, i.e. healthcare workers encounter tensions in their everyday work, and they resolve these depending on the context by muddling through with purpose. FRAM can be helpful for the study of performance variability with the aim of understanding how the ability to make trade-offs can be strengthened, and representing how the consequences of muddling through might have consequences elsewhere (either in space or time) in the system.

Example: Intravenous medication ordering

The example is taken from a project that studied safety assurance challenges of the use of autonomous infusion pumps (i.e. infusion pumps driven by artificial intelligence) for intravenous (IV) medication administration in intensive care. FRAM was one of the key methods of investigation. FRAM was used for studying work-as-done prior to the introduction of the autonomous technology in order to understand how clinicians anticipate, adapt, monitor and learn as part of everyday clinical work, i.e. how they put resilience abilities into practice. The purpose for doing this was to make recommendations that could feed into the design and implementation of the autonomous technology in such a way that its use enhances rather than diminishes resilience abilities.

The project was carried out in an English NHS hospital. The hospital serves a population of 600,000. It has a capacity of 1,131 beds, and employs over 8,800 staff. The ICU within the hospital has 16 beds, and is staffed by approximately 35 medical staff, 100 nurses and 80 support staff. The ICU cares for 1,300 patients annually. The project was concerned with IV medication management systems in the ICU. Patients on ICU are, by default, very ill. Patients can be on life support machines, such as ventilators, and they typically require a significant number of drugs. Some of these drugs are given intravenously via an infusion pump. The infusion pump controls the flow of the drug. The traditional setup is that a doctor (or clinician with prescribing privileges) prescribes a drug as part of the patient's treatment plan, and a nurse then needs to prepare the drug syringe, load the infusion pump with the drug syringe, and then program the infusion pump to run at the required infusion rate for a specific duration. This is the baseline scenario used for illustration in this chapter. A more comprehensive description of the analysis is given in (Furniss et al., 2020), and I will only refer to a small part to illustrate the approach.

The FRAM analysis identified 35 separate functions grouped into six clusters of functional activity, see Table 1.

Table 1: Functional clusters and functions for intravenous medication management

Functional Cluster	Functions
Medication ordering	Give verbal order; Write new order; Make written change to order; Do medicines reconciliation; Supervise medication management process
Infusion preparation	Check prescription; Gather equipment for preparation; Ensure medications are available and stocked; Gather drugs and fluids; Gather equipment for administration; Do drug calculations; Complete labels; Consult BNF and guidance; Prepare infusion
Interacting with patient	Inform patient about infusion details; Get consent for infusion; Do patient checks; Do visitor-supported checks
Infusion administration	Check current infusions; Go to patient; Check and flush access device; Connect lines; Get pump; Programme pump; Release roller clamp; Start pump; Administer medication; Monitor infusion; Stop and disconnect infusion; Flush line; Create plan for change to infusion
Double checking	Double check preparation and administration
Monitoring and documentation	Check previous doses; Monitor patient response; Document infusion

Following identification and description of the functions, the analysis involved description of variability as manifestation or as the observable expression of underlying resilience abilities. Hence, observed performance variability was characterised in terms of whether and how it serves as a mechanism of anticipation, adaptation, monitoring or learning. This is reflected in the structure of Table 2 below, which looks at the variability around ordering medication. The analysis of performance variability in this way can provide insights into how healthcare workers muddle through with purpose.

For example, an interesting source of variability for ordering medication is whether it is written (as per clinical protocol, i.e. work-as-imagined) or verbal, as this can have a large impact on the process downstream. The benefit of introducing this performance variability (i.e. written or verbal) is that it can deal with different kinds of demands, e.g. a verbal order is very good when there is an urgent need for treating the patient, and conversely a written order provides a clear audit trail and details for nurses to act upon. Verbal orders tend to be in the presence of the patient, e.g. during admission or when the doctor is treating the patient like putting a central line in or giving life support. After patient admission or when the treatment is complete the doctor will often sit down and do the paperwork including the prescription. Another way this variability can arise is when the nurse anticipates or responds to what the patient needs before the doctor does, and then prompts the doctor for this who can then review and write up the medication order later.

Note, that in Table 2 I include consideration of variability propagation, but in a non-normative way. The output of a function varies in line with the requirements of the situation, and this is subsequently reflected in downstream functions, either in terms of which functions are activated or when they are activated, or in additional functions being created etc. In this way, FRAM can be a useful tool to reason about the consequences of muddling through. For example, if the medication order is verbal, then it becomes necessary for the nurse to monitor (and potentially remind the doctor) that a written medication order is done at a later point in time. This is represented in FRAM through the creation of new functions.

Table 2: Performance variability in medication ordering

Manifestation of variability: what was observed?	Tensions and uncertain performance conditions: how does this demonstrate resilience?	Upstream / downstream coupling: what are the consequences of this performance variability?
There could be a written prescription or a verbal order for a drug.	There might be an emergency scenario whereby the drug has to be given immediately, or doctors may be too busy to write an order so advise that the administration proceed without it (*adaptation*).	In all cases a written order should follow a verbal order. This creates an extra function for the nurse and doctor to *monitor* that a written order follows.
The prescription/order could come before or after the administration.	Nurses may perceive a need for fluids or drugs but the doctors might not have written an order yet. For example, a continuous infusion might need to be officially reordered when the current infusion is ending but the doctors might be unavailable, so the nurse continues it in *anticipation* of an order.	Again, this creates an extra function for the nurse to *monitor* that they follow this up with the doctors and an order follows.
The prescription/order could be very specific and comprehensive about rate, dose, etc.; it could also be more general like ordering 'fluids', or incomplete.	What details are missing, how they are perceived and the demands of the context will impact the *adaptive* strategies chosen: If these are perceived as important then the doctor should be challenged. If not perceived as important the nurse will most likely get on with it, and add and/or correct details later if necessary. The urgency of the drug, its potency, and the availability of the doctor might also influence how individuals adapt. There	Challenging the doctor depends on perceived consequences (e.g. how uneasy the nurse feels about the missing information), and the availability of the doctor (e.g. if they are present or the next bed along the cost is low, if they are away from the ward they could be hard to find and might not like being interrupted).

	is a trade-off between being efficient (getting on with the task) or being thorough (making sure all information is complete and correct).	

Conclusion

In the example described, FRAM turned out to be an excellent tool for representing work-as-done, and for analysing performance variability in order to understand how success is created through resilient forms of behaviour or resilience abilities. Muddling through is done with a purpose, and I suggest that this purpose can be analysed by looking at the dynamic trade-offs that healthcare workers make in order to deal with tensions and contradictions inherent in their work and systems of work.

I conclude this chapter by acknowledging that this is a job only half done. As we gain greater insights into how people make trade-offs and how the consequences of trade-offs might impact on other functions in the system (e.g. by using FRAM), we need to turn our attention to how we strengthen healthcare workers' ability to make trade-offs. The FRAM analysis can be a useful tool for reflection for those involved in delivering and managing the work, and it can provide guidance for the design of tools and technologies. For example, if the process of intravenous infusion administration is going to be automated, then the outputs of the FRAM analysis can suggest ways in which the automation can be designed so that existing sources of resilience do not get disrupted or that resilience abilities are strengthened. There is a lot of scope for further research in this area.

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References

ANDERSON, J. E., ROSS, A. J. & JAYE, P. 2016. Modelling resilience and reasearching the gap between Work-As-Imagined and Work-As-Done. *In:* BRAITHWAITE, J., WEARS, R. & HOLLNAGEL, E. (eds.) *Resilient Health Care III: Reconciling work-as-imagined with work-as-done.* Farnham: Ashgate.

BRAITHWAITE, J., CLAY-WILLIAMS, R., NUGUS, P. & PLUMB, J. 2013. Healthcare as a complex adaptive system. *In:* HOLLNAGEL, E., BRAITHWAITE, J. & WEARS, R. (eds.) *Resilient Health Care.* Farnham: Ashgate.

EDMONDSON, A. C., KRAMER, R. M. & COOK, K. S. 2004. Psychological safety, trust, and learning in organizations: A group-level lens. *In:* COOK, K. S. & KRAMER, R. M. (eds.) *Trust and distrust in organizations: Dilemmas and approaches.* New York: Russel Sage Foundation.

ENGESTROM, Y. 1987. Learning by Expanding. Helsinki: Orienta-Konsultit.

FURNISS, D., NELSON, D., HABLI, I., WHITE, S., ELLIOTT, M., REYNOLDS, N. & SUJAN, M. 2020. Using FRAM to explore sources of performance variability in intravenous infusion administration in ICU: A non-normative approach to systems contradictions. *Applied Ergonomics,* 86**,** 103113.

HOLLNAGEL, E. 2012. *FRAM, the functional resonance analysis method: modelling complex socio-technical systems*, Ashgate Publishing, Ltd.

HOLLNAGEL, E. 2014. *Safety-I and Safety-II,* Farnham, Ashgate.

KAYA, G. K., OVALI, H. F. & OZTURK, F. 2019. Using the functional resonance analysis method on the drug administration process to assess performance variability. *Safety Science,* 118**,** 835-840.

KRAMER, R. M. 1999. Trust and distrust in organizations: Emerging perspectives, enduring questions. *Annual Review of Psychology,* 50**,** 569-598.

NUGUS, P., MCCARTHY, S., HOLDGATE, A., BRAITHWAITE, J., SCHOENMAKERS, A. & WAGNER, C. 2017. Packaging Patients and Handing Them Over: Communication Context and Persuasion in the Emergency Department. *Annals of Emergency Medicine,* 69**,** 210-217.e2.

PATRIARCA, R., DI GRAVIO, G., WOLTJER, R., COSTANTINO, F., PRAETORIUS, G., FERREIRA, P. & HOLLNAGEL, E. 2020. Framing the FRAM: A literature review on the functional resonance analysis method. *Safety Science,* 129**,** 104827.

PICKUP, L., ATKINSON, S., HOLLNAGEL, E., BOWIE, P., GRAY, S., RAWLINSON, S. & FORRESTER, K. 2017. Blood sampling - Two sides to the story. *Applied Ergonomics,* 59**,** 234-242.

RABEN, D. C., BOGH, S. B., VISKUM, B., MIKKELSEN, K. L. & HOLLNAGEL, E. 2018. Learn from what goes right: A demonstration of a new systematic method for identification of leading indicators in healthcare. *Reliability Engineering & System Safety,* 169**,** 187-198.

SCHUTIJSER, B. C. F. M., JONGERDEN, I. P., KLOPOTOWSKA, J. E., PORTEGIJS, S., DE BRUIJNE, M. C. & WAGNER, C. 2019. Double checking injectable medication administration: Does the protocol fit clinical practice? *Safety Science,* 118**,** 853-860.

SUJAN, M., HUANG, H. & BIGGERSTAFF, D. 2019. Trust and Psychological Safety as Facilitators of Resilient Health Care. *In:* BRAITHWAITE, J., HOLLNAGEL, E. & HUNTE, G. (eds.) *Resilient Health Care V: Working Across Boundaries.* CRC Press.

SUJAN, M., SPURGEON, P. & COOKE, M. 2015a. The role of dynamic trade-offs in creating safety—A qualitative study of handover across care boundaries in emergency care. *Reliability Engineering & System Safety,* 141**,** 54-62.

SUJAN, M., SPURGEON, P. & COOKE, M. 2015b. Translating tensions into safe practices through dynamic trade-offs: The secret second handover. *In:* WEARS, R., HOLLNAGEL, E. & BRAITHWAITE, J. (eds.) *The Resilience of Everday Clinical Work.* Farnham: Asghate.

VYGOTSKY, L. S. 1978. *Mind in Society*, Harvard University Press.