A Synthesis of Sociotechnical Principles for System Design

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Abstract. A set of Sociotechnical System (STS) Principles that aims to optimise both the social and the technical aspects of the work system have been derived from many STS design efforts and experiences. In particular, the sets of principles have been developed by Trist and Bamforth [35], Cherns [9, 10], Davis [14], Berniker [5], Clegg [11], Walker et al. [41], Read et al. [30] and Waterson and Eason [45]. The current paper reviewed and compared the aforementioned seventy years of mainstream sociotechnical principles for system design. The principles were identified from a systematic review, grouped by similarity, and synthesised into an updated set of principles for researchers and organisations to use and discuss. In the tradition of all previous sociotechnical principles, they seek to provide criteria for designing organisational structures, group work, work processes, design processes, technology and individual tasks. They are also used as criteria to evaluate a set of existing ergonomics methods. The fortunes of sociotechnical theory have ebbed and flowed over the past seventy years, but the value of sociotechnical principles has remained. They are now increasingly relevant to a host of distinctly 21st century problems, all of which share a common imperative to effectively integrate people and technology. A synthesis of existing sociotechnical principles is overdue.

Keywords: Sociotechnical systems theory · Sociotechnical principles · System design · Design of work systems · Joint optimisation

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1 Introduction[1]

1.1 Background and Context

Ever since the establishment of the London Tavistock Institute in 1946, Sociotechnical Systems (STS) theory has been developed and tested in order that its fundamental objective of joint optimisation can be attained. The notion of joint optimisation is shared with the field of ergonomics. It states that the social and technical aspects of a work system will produce better outcomes than if either is separately optimised [4, 35, 36].

STS design principles emerged as a novel approach for guiding the restructuring of work systems, or assessing the state of pre-existing systems, in terms of joint human and technical optimisation [28, 36]. This stems in part from action research, which is underpinned by a core idea about improving work situations in more human terms [25]. STS design principles provide guidance that analysts can translate and use on real systems [25], and this too is inspired by the same underpinnings. "Action research is intended to describe holistically what happens in naturally occurring settings, and to derive from these observations more broadly applicable principles or actionable knowledge" [2]. STS design principles show how STS theory can be converted into practical interventions. A STS design principle might state that "Design entails multiple task allocations between and amongst humans and machines" [11] or "the process of design must be compatible with its objective" [9]. Whilst not a detailed prescription of precisely what to do, they describe key STS outcomes that need to be achieved. There are several widely available STS design principles, in particular those by Trist and Bamforth [41], Cherns [9, 10], Davis [14], Berniker [5], Clegg [11], Walker et al. [41], Read et al. [30] and latterly Waterson and Eason [45]. Since 1951 they have been extended, updated and mapped across to new disciplines by subsequent researchers. Cherns' 1976 principles, for example, were updated in 1987, extended and updated by Berniker in 1996 and Clegg in 2000. The latter's principles were then mapped across to a new domain by Walker et al. in 2009, Read et al. in 2015 and again by Waterson and Eason in 2018. As it stands currently there are no fewer than 120 individual STS design principles by at least ten different authors spanning almost 70 years. The popularity of STS itself has ebbed and flowed over this period [see 44] but the attractiveness of practical and expedient STS design principles has remained. Indeed, today there is renewed interest in using it to envision work environments in new ways [19], applying it to the practical problem of workplace organisation [16, 21, 24, 37, 38], workplace safety [8, 31, 46], decision-making contexts [18], design of virtual research and development projects [26, 27], design of new governance systems [24] and addressing the numerous quality of care problems in healthcare domain [7, 17]. There is also a growing interest in what joint optimisation could do beyond 'traditional' organisational or work redesign, including everything from military command and control [40, 42] to modern debates about infrastructure resilience [43]. It is becoming apparent that joint

[1] **Practitioner summary.** The current paper has reviewed and compared 70 years of STS principles, identified the relationships between them, and synthesised them into the updated set of principles for researchers and organisations to use and discuss. It provides criteria for designing organisational structures, work processes, design processes, individual tasks, and methods.

social and technological systems are not the exclusive purview of ‘work systems’ but of ‘systems’ of all kinds [13]: from civil engineering systems through to the internet of things. Clearly, then, a lot has changed since 1946 when the first sociotechnical principles were developed, but the need for STS design principles remains. Indeed, with renewed interest comes an imperative to revisit them. In particular, a synthesis of all existing STS design principles will be of considerable benefit to researchers and practitioners going forward. This is the purpose of the current paper. In the sections that follow the wider background and context of sociotechnical theory is presented, along with a historical review of the development and foundations of STS design principles. This leads into a systematic identification of pre-existing sociotechnical principles (Table 1), a clustering and synthesis of those pre-existing principles (Table 2), culminating in a revised set of synthesised STS principles (Table 3) and a mapping onto systems ergonomics methods (Table 4).

2 Rationale for the Design of STS Principles

A principle is a proposition that serves as the foundation for a system of belief or behaviour or for a chain of reasoning. Good principles should be succinct and clear, and make it explicit what the desired outcome should be and who should action them. STS design principles are defined somewhat more loosely as “…guidelines to the ‘art of organization design” [5, 9]. In terms of desired outcomes, sociotechnical principles should enable organisations ‘to explore conflicts and complexity in the human, organisational, and technical aspects of change and to jointly optimise people and technology within a clear ethical principle’ [6, 12, 33]. Some principles do indeed describe an explicit outcome to be achieved (e.g. “design useful, meaningful, whole tasks” [42]); others take the form of a maxim or axiom (e.g. “values and mindsets are central to design”, [11]); others are more discursive (e.g. Cherns’ multifunctional principle). Perhaps the primary benefit of STS principles is to help embed a set of social values in systems that are typically viewed from a purely technological or mechanistic perspective [3, 23]. What principles ‘are not’ are prescriptions for action or a recipe to be enacted rigidly. Principles are “guides to critical evaluation of design alternatives making clear some of the differences between the sociotechnical systems approach and traditional job design” [5]. Principles “*…are not intended as design rules for mechanistic application. Rather, they provide inputs to people working in different roles and from different disciplines who are engaged collaboratively in design. They offer ideas for debate, providing rhetorical devices through which detailed design discussions can be opened up and elaborated*” [11]. In other words, sociotechnical principles are themselves ‘minimally critically specified’. The following sections describe the means by which existing STS principles were extracted from the wider literature, the method by which they were reviewed and integrated, and how the final set of synthesised principles was derived.

Table 1. Summary of the mainstream STS principles of Trist and Bamforth [35], Cherns [9, 10], Davis [14], Berniker [5], Clegg [11], Walker et al. [41], Read et al. [30] and Waterson and Eason [45]

Trist and Bamforth [35] 1951	Cherns [9, 10] 1976, 1987	Davis [14] 1977	Berniker [5] 1996	Clegg [11] 2000	Walker et al. [41] 2009	Read et al. [30] 2015	Waterson and Eason [45] 2018
1. Responsible Autonomy 2. Adaptability 3. Meaningfulness of Tasks	1. Compatibility 2. Minimal critical specification 3. Variance control 4. Boundary Location 5. Information flow 6. Power and authority 7. Multifunctionalism 8. Support congruence 9. Transitional organization 10. Incompletion	1. Systemic 2. Open system 3. Joint Optimization 4. Uniqueness 5. Philosophy 6. Quality of Working Life 7. Comprehensive Roles 8. Self-Maintaining Social Systems 9. Flat Structure 10. Participation 11. Minimum Status Differentials 12. Make Large Small 13. Design Process 14. Minimal Critical Specification 15. Action Research	1. Value clarification 2. Uncertainty 3. Choice 4. Motivated behavior 5. Participation 6. Open systems 7. Human values 8. Compatibility 9. Minimum critical specification 10. Constraint–free design 11. Self-regulating work groups 12. Responsible autonomy 13. Inducements to work 14. Boundary location 15. Boundary management 16. Joint optimization 17. Organizational uniqueness 18. Congruence 19. Variance control 20. Response variety 21. Information flow 22. Learning 23. Experimentation 24. Self-design	1. Design is systemic 2. Values and mindsets 3. Design choices 4. Design reflects needs 5. Design as social process 6. Design socially shaped 7. Design contingency 8. Process integration 9. Multiple task allocations 10. Congruence 11. Problem visibility 12. Problem control at source 13. Flexible specification 14. Design is a STS 15. Ownership 16. Evaluation 17. Multidisciplinary education 18. Resources and support 19. Political processes	1. Multidisciplinary input 2. Test implicit theories 3. Subsumption 4. Co-evolution 5. Design for adaptability 6. Whole tasks 7. Minimal critical specification 8. System DNA 9. Design is a STS 10. Users or 'prosumers'	1. Task allocation 2. Whole tasks 3. Boundary locations 4. Boundary management 5. Problem control 6. Incorporates needs 7. Intimate scale 8. Design context 9. Multifunctionalism 10.Congruence 11. Flexible specification 12. Allocation of authority 13. Flexible structures 14. Information linked to action needs 15. Agreed values and purposes 16. Resources and support 17. Appropriate design resources 18. Designing for transition 19. Choices constrain choices 20. User participation 21. Constraints questioned 22. Represent interconnectedness 23. Joint design 24. Multidisciplinarity 25. Political debate 26. Avoid fads and fashions 27. Iteration and evaluation	1. Design is systemic, emergent and context-sensitive 2. Values, organizational culture and mindsets 3. Design choices and trade-offs 4. Business and user-centred design 5. Design socially shaped, contingent process 6. Core processes integrated and components congruent 7. Flexibly specified multiple task allocations 8. Simple systems which make problems visibility 9. Problems controlled at source 10. Design practice is a dynamic, evolutionary STS 11. Resources, support and evaluation 12. Political processes

*The labels given above are abbreviations/shortened versions: full details are available in the source references.

Table 2. Synthesis of 120 existing STS principles leading to a revised set of 20 integrated principles. Shaded cells show groupings of existing principles based on similarity between them. Numbering inside the shaded cells cross refers to the specific principles listed in Table 1.

		Trist and Bamforth [35] 1951	Cherns [9, 10] 1976, 1987	Davis [14] 1977	Berniker [5] 1996	Clegg [11] 2000	Walker et al. [41] 2009	Read et al. [30] 2015	Waterson and Eason [45] 2018	Commonality
1	Multifunctionalism	2	7	7	20	9	5	1, 9	7	**8/8**
2	Congruence		8	5	13, 18	10, 18	1, 8	10	6, 11	**7/8**
3	Flexible specification		2	14	9	13	7	2, 11	7	**7/8**
4	Joint optimisation		1	3	16	1	1	23	1, 6	**7/8**
5	Participation		1	10, 11	5, 8	15	10	20	4	**7/8**
6	Designing design		2, 9	1, 2, 15	3, 6	1, 3, 14		17, 18, 19, 22, 27	3, 10	**6/8**
7	Experimentation		10	15	22, 23	16		5, 27	1	**6/8**
8	Flux		10		24	5, 14	5	18, 27	10	**6/8**
9	Responsibility	1	6	11	12	8		12		**6/8**
10	Values		8	6	1, 7, 13, 15	2		15	2	**6/8**
11	Boundaries		4	12	14, 15	8		3, 4		**5/8**
12	Constraints		2		10	6, 19		21, 25, 26	5, 12	**5/8**
13	Multidisciplinarity		10	13		17	1	24		**5/8**
14	Resource flows		5		21	8	9	14, 16		**5/8**
15	Uniqueness			4	17	7	3	8		**5/8**
16	Variance control		3		2, 19	12		5	9	**5/8**
17	Functional purposes				7	4	4	6, 15		**4/8**
18	Job characteristics	3			4		6	2		**4/8**
19	Simplicity and scale					11	2	7	8	**4/8**
20	Self-regulation			8, 9	11			13		**3/8**
	Total principles	**3**	**9 (1976)** **10 (1987)**	**15**	**24**	**19**	**10**	**27**	**12**	

Table 3. Synthesised set of sociotechnical system design principles

	Principle	Proposition
1	Multifunctionalism	Human agents* should be skilled in more than one function
2	Congruence	System designers should ensure that support systems and sub-systems are congruent with the basic system design
3	Flexible specification	Human agents* should be provided with the outcome to be achieved but the means to achieve it minimally critically specified
4	Joint optimisation	System designers should give equal consideration to the role of humans and technology in systems
5	Participation	System designers should match democratic work structures with democratic design processes
6	Designing design	System designers should recognise that the design process for STS is itself an STS and can be treated as such
7	Experimentation	System designers should treat design iterations as ‘experiments’ and act on the results of those experiments
8	Flux	System designers need to recognise that systems are by their nature dynamic and never ‘complete’, and this requires continuous re-evaluation
9	Responsibility	Human agents* should be given responsible autonomy for carrying out tasks
10	Values	System designers should express the aspirations and needs of people within their design criteria
11	Boundaries	System designers should ensure that system boundaries do not interfere with the exchange of information and learning
12	Constraints	System designers should identify social, technical and political issues which constrain or enhance choices
13	Multidisciplinarity	System designers should draw from a diverse range of expertise, skills and perspectives
14	Resource flows	System designers need to ensure that information is provided at the point at which it required
15	Uniqueness	System designers should recognise that each system is different and these differences should not be neglected
16	Variance control	System designers should enable variances to be controlled from the point where they originate
17	Functional purposes	System designers should ensure it is designed to support the fundamental reason it exists; that fundamental reason needs to be made explicit
18	Job characteristics	System designers should design human roles within systems that involve a full, coherent and meaningful cycle of activities
19	Simplicity and scale	System designers should minimise complexity and maximise ease of use and understanding
20	Self-regulation	System designers should examine the conditions under which individuals or groups become self-regulating, and try to optimise those conditions

*In the not too distant future it is conceivable this could apply equally to autonomous agents, AI, etc.

Table 4. Ergonomic methods aimed at the comprehensive analysis of STS assessed against the new synthesised STS principles. 'XX' denotes that a method addresses a given principle, 'X' denotes that it 'partially addresses' the principle, and a blank cell denotes that the method does not address a principle.

	Label	CWA	STAMP[a]	EAST	FRAM	ACCIMAP	HTA
1	Multifunctionalism	**XX**		**XX**	**XX**	**XX**	**XX**
2	Congruence	**XX**	**X**	**XX**	**XX**	**XX**	**XX**
3	Flexible specification	**XX**					**XX**
4	Joint optimisation	**XX**	**X**	**X**	**XX**	**X**	**XX**
5	Participation	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
6	Designing design	**X**	**X**	**X**			**XX**
7	Experimentation	**XX**	**X**	**XX**	**XX**		**XX**
8	Flux	**XX**	**X**	**X**	**X**	**X**	**X**
9	Responsibility	**XX**	**XX**	**XX**		**XX**	**XX**
10	Values	**XX**					
11	Boundaries	**X**	**X**	**X**	**X**	**XX**	**X**
12	Constraints	**XX**	**X**	**X**		**X**	**X**
13	Multidisciplinarity	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
14	Resource flows	**X**	**XX**	**XX**	**XX**	**X**	**X**
15	Uniqueness	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
16	Variance control	**X**	**XX**		**XX**	**X**	**X**
17	Functional purposes	**XX**		**X**			**X**
18	Job characteristics	**X**					**XX**
19	Simplicity and scale	**X**	**X**				**XX**
20	Self-regulation	**X**	**X**				**X**
	Totals	33	22	22	20	19	31

[a]With particular emphasis on the STPA aspect of STAMP
[b]Includes the numerous methods which make use of the outputs of HTA (i.e. not HTA alone)

3 Method

A large-scale literature search was undertaken to reveal all instances of STS principles extant in the publically available and peer-reviewed knowledge-base. The high-level search topics centred on four areas: (1) sociotechnical system design approaches, (2) sociotechnical system design in work systems, (3) principles of sociotechnical system design, (4) organisational behaviour.

General principles of design, or principles founded on different (and possibly incompatible) value-bases or domains except STS were excluded from the review. A mixed search strategy was employed, combining features of a systematic review with a more flexible and opportunistic approach. This ensured rigour on the one hand but also the flexibility to draw from cross - disciplinary literature in cases where search terms may not be present despite there being clearly relevant insights to draw from.

The following databases were accessed: Science Direct, Taylor and Francis, Google Scholar, Open Science Index, Semantic Scholar, BASE, OpenAIRE, WorldCAT, Sherpa/RoMEO, Zenedo.

This approach provides confidence that mainstream STS principles were harnessed, i.e. those that have enjoyed relatively widespread use and are available in the public domain. The authors acknowledge there may be STS principles of a more specialist and proprietary nature in existence. The completed review spanned the foundational work in STS principles dating from the field's inception in the 1940's and 50's and its precursors in scientific management approaches, though to the present day. In total 237 articles met the criteria above and were reviewed in depth. These articles included the prominent STS work of Trist and Bamforth [35], Cherns [9, 10], Davis [14], Berniker [5], Clegg [11], Walker et al. [41], Read et al. [30] and Waterson and Eason [45]. The review also shed light on the origins behind the principles, how they had been deployed in practice, and any subsequent revisions. This depth of knowledge was vital for the process of integrating and synthesising the principles.

4 Synthesised Principles for Sociotechnical Systems Design

Table 1 provides a summary of the mainstream STS design principles currently extant in the literature. Two high-level findings emerged from the review. Firstly, the principles put forward by Trist et al., Cherns, Davis, Berniker, Clegg, Walker et al. and to a lesser extent Read et al. are quite persistent in the literature. They have tended to express the prevailing STS viewpoints of the day and been used in comparatively unmodified form. There are no other comprehensive sets of STS principles that have been widely published and used that diverge from these mainstream ones to a significant degree. Secondly, it is clear that comparatively little work has taken place synthesising these existing principles. To some extent the principles have grown from and built on previous versions as the underlying STS knowledge-base has itself grown, but apart from Read et al. [30] they have not been comprehensively integrated or synthesised into a common list. Table 2 goes on to present a matrix showing how the existing mainstream STS design principles can be grouped into a reduced number of themes based on their similarity. Table 2 also enables these groupings to be traced. The numbers in the cells show precisely which principles from Table 1 relate to which of the reduced themes in Table 2. These reduced themes then go on to form the synthesised list of STS principles elaborated and described in Table 3.

Many areas of commonality and distinctiveness are revealed in Table 2. The themes have been rank ordered to show which ones are more heavily loaded with pre-existing principles (e.g. multifunctionalism, congruence, joint optimisation, flexible specification etc.) or lightly loaded (e.g. simplicity and scale, self-regulation etc.). A mean of 5.6 out of 8 component principles load on to the reduced set of themes, reinforcing the point that the principles have more in common than they differ. It should also be added again that Tables 1 and 2 provide complete traceability, making it possible for the wider research community to scrutinise and, if necessary, revise these categorisations. For now, though, it is from this underlying structure that a fully up to date and synthesized list of 20 principles (see Table 3) can be derived.

An early use to which these principles can be put is in the assessment of existing ergonomics methods. Such an assessment is performed in Table 4. Here the principles are used to assess five contemporary systems ergonomics methods, all of which purport to support the analysis of STS. The methods are Cognitive Work Analysis (CWA) [29, 39, etc.], Systems-Theoretic Accident Model and Processes (STAMP) [22, 47, etc.], Event Analysis for Systemic Teamwork (EAST) [32, 34, etc.], Functional Resonance Analysis Method (FRAM) [20, etc.]. Also included is Hierarchical Task Analysis (HTA) [1, 32, etc.] a foundational method in ergonomics but one that drives a wide range of additional methods relevant to STS. This exercise is emphatically not about pitching one method against another in a form of competition, rather to flush out the different perspectives on STS each is able to provide. Clearly some methods are more comprehensive than others. CWA, for instance, provides a particularly wide ranging insight into relevant STS dimensions. Indeed, CWA seems to be one of the few that grants access to principles such as values (principle 10) and functional purposes (principle 17). It is interesting to note that HTA, when combined with the numerous methods that rely on its outputs, also provides comprehensive coverage of STS principles. As noted earlier, if there is a strategic need for the ergonomics discipline to become more engaged with high quality systems problems [e.g., 15] and for progress to be made in systematising STS practices and principles [e.g., 11] then ergonomic methods clearly have much to offer. Future research is being directed into a much more comprehensive STS methods review, using the new synthesised STS principles as evaluation criteria.

5 Conclusion

The current work has reviewed and compared 70 years of STS principles, identified the relationships between them, and synthesised them into updated set of principles for researchers and organisations to use and discuss. These principles, in the tradition of all previous STS principles, provide criteria for designing organisational structures, group work, work processes, design processes, technology, individual tasks, and methods. The principles are offered for use by anyone involved in organisational and system design, and should help to illustrate differences between traditional work design and the sociotechnical approach. The principles also provide direction to the system design process, providing a lens through which existing organisations and systems can be examined and new ones designed from scratch. The 70 year legacy of research which underpins these principles provides confidence that sociotechnical design principles will contribute to enhanced levels of performance, including operational measures such as productivity and effectiveness, but also psychological indicators concerned with well-being and attitudes. It is hard to deny that many organisations currently lack an integrated approach to organisational and technical change which, in the worst cases, results in a range of organisational pathologies right through to major system failures. As organisations become larger, more complex and more highly integrated, combined with dramatic changes in technology, the cost of such failures increases rapidly. Improving the existing set of sociotechnical principles provides a significant opportunity to cope with these emerging challenges in a more enlightened way. At the simplest level it is possible to regard every single STS design principle as a possible risk, but at the same time they are also an opportunity.

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