To Shower or Not to Shower: A Behavioural Model of Competition for Shared Resources

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Abstract

Most system dynamicists have used a simple shower model to explain feedback and to introduce cyclical dynamic behaviour characteristic of a balancing loop. The damped system's temperature is relatively easy to manage. But what if we assume the existence of two showers sharing the same limited supply of hot water? It turns out - as one might expect - that it is much harder to control the water temperature, because a person 'managing' one shower is unaware of the other shower or its occupant, yet must react to the aggregate temperature outcome resulting from a joint 'management' effort.

We discuss how a simple two-shower model can provide a useful metaphor for a wide range of real managerial problems. The model is used to illustrate the causes and consequences of interdependence in processes of resource allocation, competition and cooperation within and among organisations.

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Introduction

"The situations in which people's behaviour or people's choice depends on the behaviour or choice of other people, are the ones that don't permit any simple summation or extrapolation to aggregates. To make that connection we usually have to look at the *system of interaction* between individuals or between individuals and the collectivity. And sometimes the results are surprising" (Schelling, 1978; 14. Emphasis in the original).

One of the continuing sources of inefficiency in modern business organisations is the allocation of common resources in situations where a person's decision alters the frame of reference for others, i.e. in situations characterised by diffused positional externalities (Frank, 1991).[1]

Externalities pose two basic problems for the management of resource allocation processes in organisations. The first problem is that inefficiencies systematically arise because boundedly rational decisionmakers cannot possibly take into full account all the costs and benefits of their interdependent actions (Simon, 1976). Specifically, bounded rationality implies that decisionmakers cannot (a) compute the costs that accrue to other people (or parts of the organisation), and (b) experience the consequences of their actions immediately and directly, but only with delay through a complex chain of ambiguous events (March and Olsen, 1976). The second problem is that specific individuals and groups are often in a position to bring off (or defend) suboptimal allocations that satisfy local interests, but that may be collectively worse than the target efficient allocation.

The pervasiveness of externalities in organisational life has encouraged the conceptualisation of the process of resource allocation (among alternative projects, subunits, or activities) as a situation of pure conflict (zero sum game) where managers compete for the control of scarce internal resources (Milgrom and Roberts. 1992). However, in actual managerial decisions, motives for conflict are often intertwined with the need for cooperation. The process of resource allocation can be more accurately characterised as a mixed-motives game not because players have unclear preferences or objectives, but rather because of the ambiguity of the relation among players which involves potential competition, potential partnership, and dependence from common resources (Schelling, 1980).

To overcome the indeterminacy inherent to this situation, formal theories of bargaining assume that the relevant actors engage in strategic negotiations with clearly identified potential partners/rivals whose behaviour they react to and with whom - in the end - they either reach an agreement or "agree to disagree". (Aumann, 1976). But what happens when individual decisionmakers can only experience the result of the interaction between their previous actions and the action of others? In other words, what happens when individual decisionmakers are part of the environment they are supposed to respond to?

In this paper we show that in this more ambiguous (and we argue, realistic) situation individual behaviour tends to add up to collective results that none of the actors involved would have chosen. We develop a dynamic model of a two shower system where users share a common resource (hot water), and adjust the temperature to reach a desired target. The two shower model is a metaphor for more complex organisational resource allocation. Using this metaphor we identify the existence of externalities and time delays as the underlying causal mechanisms responsible for "[t]he frequent divergence between what people are individually motivated to do and what they might like to accomplish" (Schelling, 1978,128). Finally, we illustrate the role of mental models in ambiguous decision making situations characterised by resource sharing.

The remainder of the paper is organised in six parts. The first part illustrates the basic feedback structure at the heart of shower systems - the so-called balancing loop with delay. Part two describes

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[1] From a strictly economic point of view, a given allocation of resources is efficient if there is no other allocation that makes someone better off without making another person worse off. Inefficient allocations are wasteful since - by making better use of the available resources - it would be possible to make somebody better off without hurting anybody else.

in detail the operating structure of a single shower. Part three simulates the dynamic behaviour of a single shower. Part four of the paper introduces a two-shower model, and explains in detail its coupling formulations. Part five reports simulations of the two-shower model, focusing on the consequences of competition for shared resources. Finally, part six explores the implications of the two-shower simulations for our understanding of cooperation and competition in organisations, and outlines some directions for future research.

Balancing loop with delay, showers and resource allocation

One of the first conceptual models shown to anyone who is entering the area of system dynamics is the 'sluggish' shower. It represents a situation most people have experienced and illustrates the sometimes baffling influence that time delays can have on otherwise simple judgemental decisionmaking tasks. Figure 1 shows a circle diagram (or causal loop diagram) for a sluggish shower. The temperature gap represents discomfort in the shower - the current water temperature is, say, lower than desired. As a result, the person in the shower adjusts the tap setting, which eventually (after a time delay) increases the flow of hot water and therefore the current water temperature. The decisionmaking task in the shower is to keep yourself comfortable. The difficulty of this task depends on the time delay in the shower's plumbing, spanning the interval from when you make a change in the amount of hot water to when you feel the difference. Senge (1990) describes succinctly the confounding effect of such delays: "Unrecognised delays can [also] lead to instability and breakdown, especially when they are long. Adjusting the shower temperature, for instance is far more difficult when there is a ten second delay before the water temperature adjusts, than when the delay takes only a second or two. During that ten seconds after you turn up the heat, the water remains cold. You receive no response to your action: so you perceive that your act has had no effect. When the hot water finally arrives, a 190-degree (fahrenheit) water gusher erupts from the faucet. You jump out and turn it back; and, after another delay, it's frigid again. On and on you go, through the balancing loop process". Fortunately, (at least in single showers) most people eventually bring the system under control. In other words they find a stable tap setting that results in an acceptable temperature (see Lane 1992 for a curious exception).

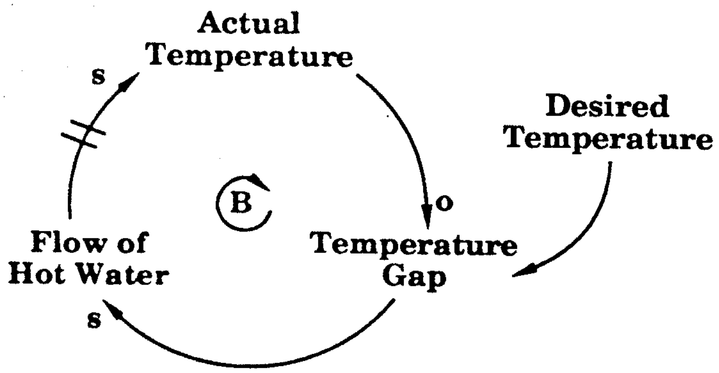

Figure 1 *The "classic" causal loop diagram for a sluggish shower.*

One reason why most people succeed in controlling such a system is that there is a direct, albeit delayed, causal link between their action - the change in the flow of hot water, and the outcome - the change in actual water temperature. However, there are relatively few cases in the "real" world where you manage your "own" system, completely isolated from (and independent of) the decisions and actions of anyone else. The alternative to independence is interdependence where your behaviour and actions influence not only your world, but also the world of other players who then react to the changes they are experiencing (Morecroft, 1983).

Systems which have these properties of interdependence are common in business and social affairs, covering situations that involve the allocation of scarce shared resources such as cash, time, market share, capacity and even political votes. Our "two-shower world" is a metaphor for these more complex worlds. The scarce shared resource is hot water. We can all readily envisage what might happen if my tap setting (in my shower), affects your comfort (in your shower), and vice versa. In this mutually dependent world there is no longer a simple causal relationship between my action (changing the amount of hot water) and the outcome (change in temperature). The outcome is now also influenced by the conditions in your shower, and the decisions you make as a consequence. It becomes increasingly hard for either of us to understand the relation between the change in the flow of hot water and the change in temperature - in fact so baffling that both of us could fail completely to achieve a satisfactory, comfortable and stable temperature, no matter how long we spend in the shower adjusting the tap setting!

Representing the balancing loop in a single shower - map and friendly algebra

The first step in simulating a two-shower world is to develop a plausible representation of a single shower.

Try to visualise such a shower. In front of you there is a tap or lever that regulates water temperature by adjusting the flow of hot water in relation to a fixed flow of cold water. The tap turns from left to right across an angular scale that is marked cold on the left and hot on the right.

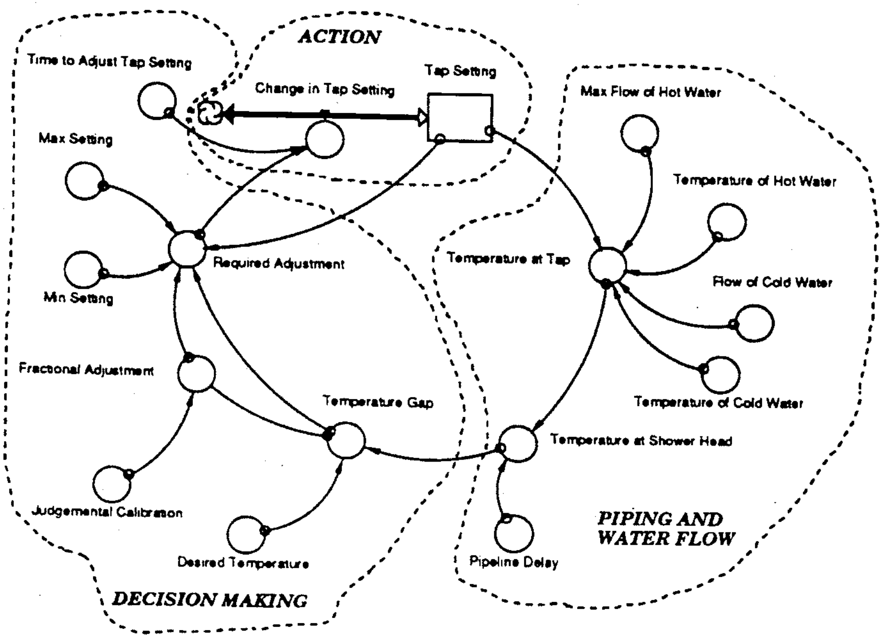

Figure 2 *A flow diagram of the single shower model.*

Figure 2 shows the operating structure and Figure 3 the equations of the shower system involving the tap, the plumbing, the flow of water and the decision making of you, the person in the shower. Let's get into the shower and talk through the operating structure. The temperature gap is the difference you sense between desired temperature (at which you feel comfortable) and the actual temperature at the shower head. In the equations desired temperature is set at 25 degrees Celsius. The symbols on the left hand side of the map show how the recognition of a temperature gap leads to a change in tap setting. This part of the map represents your decision making, as a 'rational' shower taker who wants to stay comfortable.

The temperature gap leads you to contemplate a fractional adjustment to the tap setting. Imagine what goes through your mind. The water temperature is too cold. So you decide to turn the tap part way round the scale in a direction that you believe will warm you up. In the equations this judgemental fractional adjustment is proportional to the temperature gap - the more degrees you are away from comfort, the greater the fractional adjustment you envisage, according to your judgemental calibration of the scale for the tap setting.

Your thinking moves one step closer to action as you gauge the required adjustment to the tap setting. You glance at the tap and note its current setting and the maximum and minimum settings to which it can be turned. If you feel too cold (temperature gap greater than zero) then you turn the tap toward the hot end of the scale. But how far should you turn the tap between the current and maximum setting? Here your judgement is key to your later comfort! In the model the required adjustment is equal to the difference between the maximum and current tap setting (your 'room for manoeuvre', or angular distance remaining, on the scale) multiplied by the fractional adjustment (your estimate of the appropriate turn of the tap as a fraction of the remaining angular distance on the scale). If you feel too hot then you follow a similar line of reasoning in gauging how far to turn the tap between the current and minimum setting.

All these thoughts, comprising your judgement on tap setting, flash through your mind in an instant. In fact you are scarcely aware of the steps in the judgement. What you know and feel is a sensation of being too cold or too hot, and so you turn the tap. In the model the change in tap setting is set equal to the required adjustment divided by the time to adjust the tap setting. This portion of the map represents the part of the shower system where your judgement and decision making converts into action. Your hand turns the tap and the tap setting changes. The angular movement of the tap accumulates in a level that represents the position of the tap on the hot-cold scale. Then the plumbing takes over, and you await the consequences!

On the right hand side of the figure the water temperature at the tap is shown to depend on the tap setting. Algebraically, the temperature at the tap depends on the flow of cold water, the temperature of the cold water, the tap setting, the maximum flow of hot water, and the temperature of the hot water. The equation looks quite complex, but really it is just blending two flows of water, cold and hot, and calculating the resultant temperature. The flow of cold water is fixed at 15 litres per minute, at a temperature of 10 degrees Celsius. The maximum flow of hot water is set at 30 litres per minute, at a temperature of 70 degrees Celsius. The volume of hot water in the shower is a fraction of this maximum flow, determined by the tap setting. As the tap setting changes from its minimum value of 0 (the cold end of the scale) to its maximum value of 1 (the hot end of the scale) then the water temperature moves from its minimum value of ten degrees Celsius to its maximum blended value of fifty degrees Celsius (a weighted average of ten degree and seventy degree water).

The temperature at the shower head changes with the temperature at the tap, but only after a time delay, which is literally the pipeline delay in the pipe connecting the tap to the shower head. In the model the pipeline delay is set at 4 seconds.

As the water emerges from the shower head, we come full circle around the map, back to the temperature gap.

```
Tap_Setting(t) = Tap_Setting(t - dt) + (Change_in_Tap_Setting) * dt
 INIT Tap_Setting = 21/60
          {dimensionless fraction of scale range}
Change_in_Tap_Setting = Required_Adjustment/
Time_to_Adjust_Tap_Setting
          {fraction range of scale remaining /second, which reduces
          dimensionally to 1/time}
Desired_Temperature = 25
          {°C, the temperature at which the person in the shower feels comfortable}
Flow_of_Cold_Water = .25
          {litres per second, which is equivalent to 15 litres per minute}
Fractional_Adjustment = ABS(Temperature_Gap*Judgemental_Calibration)
          {fraction of scale range remaining, where Temperature_Gap has the
          dimension of °C and Judgemental_Calibration has the dimension of
          fraction of range/°C}
Judgemental_Calibration = 1/10
          {fraction of scale remaining/°C, the judgemental calibration of the tap
          scale by the person in the shower, represented as a fractional
          adjustment of tap setting within the visible scale remaining, per °C t
          emperature gap}
Max_Flow_of_Hot_Water = .5
          {litres per second, which is equivalent to 30 litres per minute}
Max_Setting = 1
          {dimensionless }
Min_Setting = 0
          {dimensionless }
Pipeline_Delay = 4
          {seconds, the time it takes for hot water to move through the pipe
          connecting the tap to the shower head}
Required_Adjustment = If Temperature_Gap > 0 Then (Max_Setting-
Tap_Setting)* Fractional_Adjustment Else (Min_Setting-Tap_Setting)*
Fractional_Adjustment
          {fraction range of scale remaining }
Temperature_at_Shower_Head =
SMTH3(Temperature_at_Tap,Pipeline_Delay)
          {°C}
Temperature_at_Tap = Flow_of_Cold_Water*Temperature_of_Cold_Water
+Tap_Setting* Max_Flow_of_Hot_Water*Temperature_of_Hot_Water/
(Flow_of_Cold_Water+Tap_Setting*Max_Flow_of_Hot_Water)
          {°C}
Temperature_Gap = Desired_Temperature-Temperature_at_Shower_Head
          {°C}
Temperature_of_Cold_Water = 10
          {°C}
Temperature_of_Hot_Water = 70
          {°C}
Time_to_Adjust_Tap_Setting = 6
          {seconds, the time taken to adjust the tap setting, combining both the
          judgemental delay and the physical delay in moving the tap}
```

Figure 3 *The equations for the single shower model.*

To summarise, the single shower model is represented in three parts. On the left of the map is the behavioural decisionmaking process that translates a temperature gap into a required adjustment of the tap setting. At the top of the map is the action of adjusting the tap that leads to a new tap setting. On the right of the map is the piping and water flow that converts the tap setting into hot water at the shower head.

Simulation of the single shower model

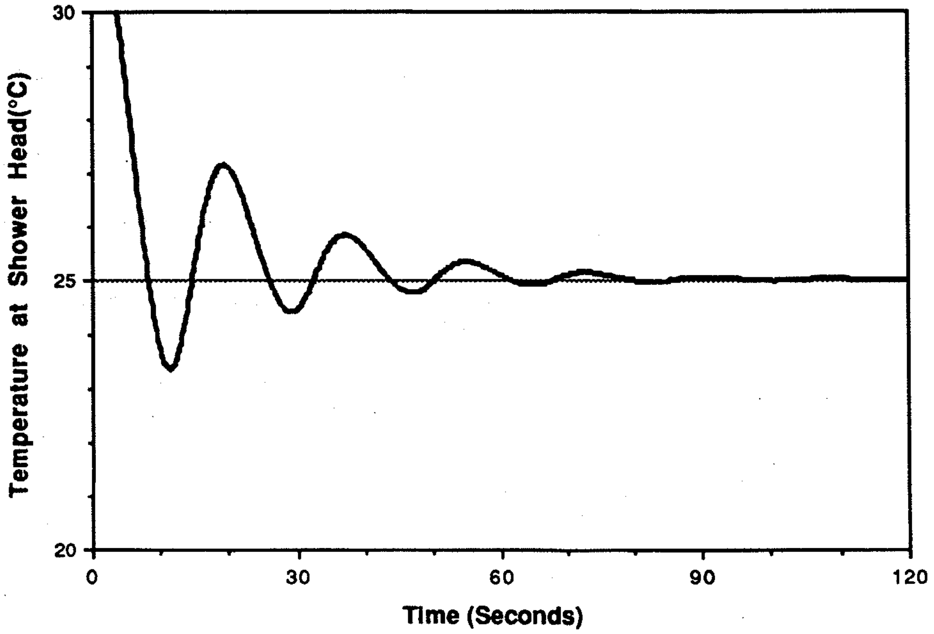

Figure 4 *A graph showing the temperature in the single shower model.*

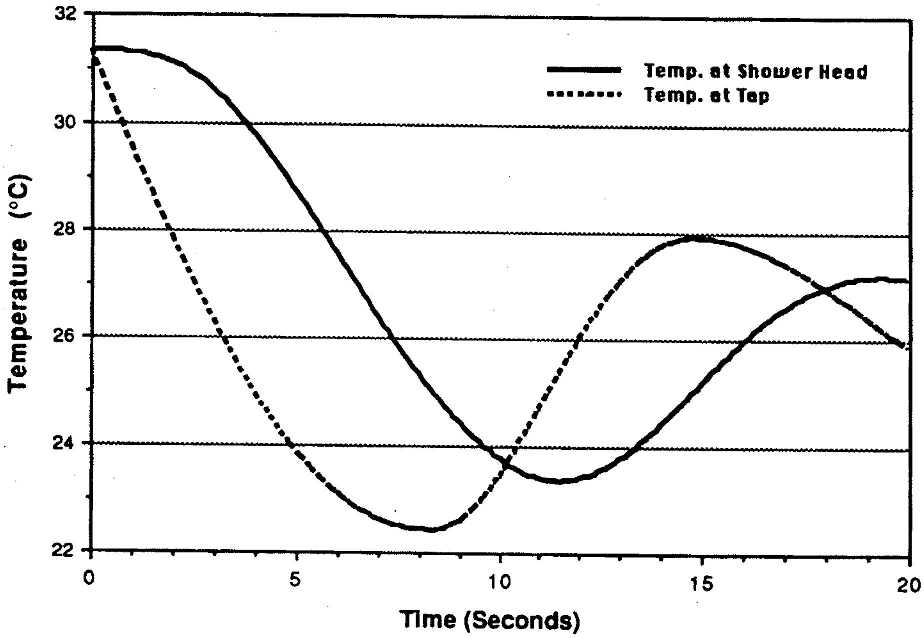

Figure 5 *A graph showing the difference between temperature at the tap and the shower head.*

hot water to shower 1, and vice versa -- an extreme assumption in a shower, but quite plausible in business or social systems that share a common resource, for which the modelled shower system is a metaphor.[2]

The maximum flow of hot water available to shower 1 is the product of the fraction of hot water available to shower 1, and the maximum flow of hot water in the system as a whole (the shared resource constraint). Given the maximum flow of hot water to shower 1, the remainder of the equations for piping and water flow are identical to the one shower system.

```
Flow_of_Cold_Water = .25
        {litres per second, which is equivalent to 15 litres per minute}
 Frac_Hot_Water_Available_to_1 = Tap_Setting_1/(Tap_Setting_1
+Tap_Setting_2)
        {dimensionless}
 Max_Flow_of_Hot_Water = 1
        {litre per second, which is equivalent to 60 litres per minute}
 Max_Flow_of_Hot_Water_to_1 = Max_Flow_of_Hot_Water*
Frac_Hot_Water_Available_to_1
        {litres per second}
 Temperature_at_Tap_1 =
Flow_of_Cold_Water*Temperature_of_Cold_Water+Tap_Setting_1
*Max_Flow_of_Hot_Water_to_1*Temperature_of_Hot_Water/(Flow_of_Cold
_Water+Tap_Setting_1*Max_Flow_of_Hot_Water_to_1)
        {°C}
 Temperature_of_Cold_Water = 10
        {°C}
 Temperature_of_Hot_Water = 70
        {°C}
```

Figure 7 *The "coupling" equations for shower 1 in the two shower model.*

The coupling equations for shower 2 are similar to shower 1, but expressed in terms of the tap settings as they affect the flow of hot water in shower 2. So, the fraction of hot water available to shower 2 is represented algebraically as the ratio of tap setting 2 to the sum of tap setting 2 and tap setting 1.

Simulations of the two shower model

We have selected two simulations of the two shower model to explore the consequences of boundedly rational behaviour in mutually dependent systems. The first simulation is a very special case, a benchmark, in which dynamic behaviour in the two shower system is identical to the single shower case despite the coupling. (Because the behaviour is identical to the single shower case, the reader is referred back to figure 4 to see the simulated temperature trajectory). To generate this outcome both shower systems must be identical in every respect: desired temperature, judgemental calibration, initial tap settings, cold water flows and pipeline delay. When such perfect symmetry exists in the coupled shower worlds, then each decisionmaker's judgemental choices and actions are precisely (though unintentionally) coordinated - they are both equally sensitive to temperature gaps and they make simultaneous, identical adjustments to the tap settings. So they always share the hot water

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[2] In reality, strong coupling is unlikely across the full range of tap settings in a domestic two shower system. Showers are designed to derive their hot and cold water supplies from a constant pressure source -- a source which is capable of boosting the maximum flow of water to accommodate different tap settings. However, in most plumbing systems (which invariably supply water for many simultaneous uses), the supply of hot water, and sometimes the supply of cold water, can become constrained. As the supply constraint is approached, the dynamic water pressure in the pipes falls thereby reducing the flow of water in a way that (we believe) approximates the algebraic formulations used in this paper. The authors are grateful to Mr. R. L. Piggot, a professionally qualified plumber living and working in Beaconsfield, for his explanations of constant pressure plumbing systems. The authors admit that they still have a lot to learn about the science and art of plumbing.

supply on a 50:50 basis. Their coupled world behaves (from the point of view of each shower taker) like two independent worlds.

```
Flow_of_Cold_Water = .25
        {litres per second, which is equivalent to 15 litres per minute}
Frac_Hot_Water_Available_to_1 = Tap_Setting_1/(Tap_Setting_1
+Tap_Setting_2)
        {dimensionless}
Max_Flow_of_Hot_Water = 1
        {litre per second, which is equivalent to 60 litres per minute}
Max_Flow_of_Hot_Water_to_1 = Max_Flow_of_Hot_Water*
Frac_Hot_Water_Available_to_1
        {litres per second}
Temperature_at_Tap_1 =
Flow_of_Cold_Water*Temperature_of_Cold_Water+Tap_Setting_1
*Max_Flow_of_Hot_Water_to_1*Temperature_of_Hot_Water/(Flow_of_Cold
_Water+Tap_Setting_1*Max_Flow_of_Hot_Water_to_1)
        {°C}
Temperature_of_Cold_Water = 10
        {°C}
Temperature_of_Hot_Water = 70
        {°C}
```

Figure 8 *A graph showing the temperature in the two showers.*

But in reality there are many ways in which small differences can appear in the plumbing, the flow of water and the behavioural decisionmaking. The second simulation shows what happens when there is a small difference in the judgemental calibration of the two shower takers (Figure 8). The person in shower 1 turns the tap more than the person in shower 2 for any given temperature gap. The result is dramatic. Figure 8 shows the simulated behaviour of temperature at the two shower heads over a period of two minutes (120 seconds). Neither shower taker is able to achieve a condition of stable and comfortable 25 degree water, despite the clear intention of both to do so. Instead of converging toward the common comfort level, the water temperature in both showers actually exhibits divergent fluctuations, repeatedly reaching peaks of more than 35 degrees and troughs of less than 20 degrees. The strong coupling of the shower worlds is evident in the way temperature movements mirror each other - when temperature is high in shower 1, it is low in shower 2, and vice versa.

Such a world is confusing and frustrating for decisionmakers (Sterman 1989). Well intentioned actions to stabilise temperature (and so increase comfort) have the perverse effect of inducing ever greater instability. Moreover, no amount of time spent changing the tap setting will improve the situation. Each shower taker adopts an 'adjustment strategy' and mindset appropriate to a single shower, reinforced by visual cues that confirm they are in a single shower world - separate cubicles, a single tap to adjust, no awareness of the other shower or its occupant (just like the functional 'stovepipes' that shape mindsets in organisations).

Implications of the two shower model for understanding cooperative and competitive behaviour
How can shower takers in their isolated yet coupled worlds improve the unsatisfactory behaviour that their well intentioned decisions and actions produce? Are there ways to achieve better coordination? If so, what are the transferable lessons for organisations sharing common but limited resources.

The two shower system poses its occupants with an apparent dilemma - how to reconcile global thinking (the attempt to 'take into account' the larger system of which one is a part) with local action (which is strongly conditioned by local conditions - in this case the local temperature gap) (Lomi and Larsen, 1994). Effective global thinking often requires one to take local action that appears to contradict one's local needs. In the two shower system a much more gradual response of tap setting to any given temperature gap by both occupants should help them achieve their local desire for temperature stability, even though moving the tap quickly seems to be the 'logical' thing to do. This contradiction probably stems from deeply ingrained mental models of simple cause and effect that tell us 'if you are too cold then obviously you should increase the hot water supply, and vice versa'.

You can't change mental models in an instant. But you can provide decisionmakers with cues and additional information that make them more aware of complexity and interdependence. In a two shower system the first step is simply to be aware of the other shower occupant. Knowing that someone shares your hot water supply could be a sobering thought as you turn-up the tap setting. Actually seeing, in your shower, a display of the water temperature in the other shower, may help you visualise the interdependence of your shared world. Here are the seeds of collaboration and cooperation - providing that limits of information processing do not preclude the intelligent use of coordinating information.

Organisational systems likewise are characterised by intendedly rational behaviour, limited resources, local mental models, imperfect coordination, and limits to information processing (Morecroft, 1985 and 1986). As with the shower system, modelling and simulation can help explore dysfunctional behaviour, expand mental models and build shared understanding as the basis for productive collaboration. In future work we intend to explore in more depth the simulated behaviour of the two shower system and to investigate the impact of design changes intended to improve coordination of shower takers' decisionmaking. Building on this work we hope to re-examine dynamic behaviour and policy design in existing and new models that represent explicitly the management of shared resources.

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