Overview, Design concepts, and Details + Decision making (ODD+D) for the instantiation of a model for a work environment and workers with Two-Factor Theory.

This document describes fundamental aspects of an agent-based model (ABM) of a multi-unit work environment and its workers following the ODD protocol developed by Grimm et al (2006) and the decision making extensions developed by Müller et al (2013). The model presented here is the first explicit instantiation of the Two-Factor Theory (Herzberg et al., 1959) of worker satisfaction and dissatisfaction. By utilizing agent-based modeling, it allows users to test the empirically found variations on the Two-Factor Theory to test its application to specific industries or organizations. In Figure 1 we show the graphical user interface (GUI) of the model. On the left-hand side we have user-specified inputs to replicate empirically-derived variations of the application of the two-sets of factors identified in the theory. The right-hand side of the GUI is an abstract representations of the workers and their work units. NetLogo 6.1 (Wilensky, 1999) was used to implement the model.

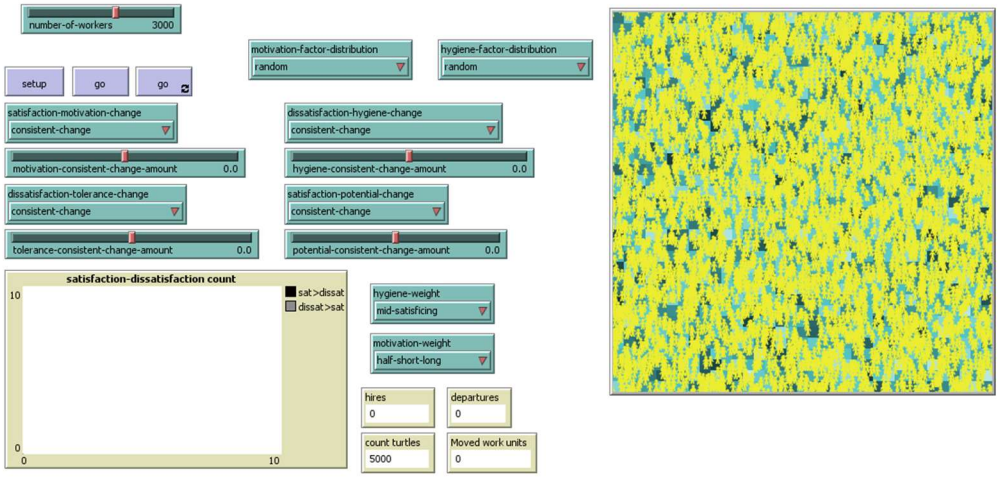


Figure 1: Graphical User Interface of the Model.

1 Overview

1.1 Purpose

Our motivation for implementing an ABM instantiation of the Two-Factor Theory (Herzberg et al., 1959) comes from the decades of real-world testing of the theory's applicability (e.g., Bassett-Jones & Lloyd, 2005; Hasin & Omar, 2007; Dobre, et al., 2017) and the possible efficiencies could be gained by first testing the parameters of the experiment *in silica.* The Two-Factor Theory as originally developed and tested by Herzberg et al. (1959), which explore two sets of five factors each that consistently led to worker satisfaction and dissatisfaction levels, respectively. The two sets of factors are motivation factors and hygiene factors. The motivation

factors contribute to worker satisfaction, while the hygiene factors contribute to worker dissatisfaction. Motivation factors which are shown in Table 1 revolve around the worker's understanding of himself in the work and include achievement, recognition, the work itself, responsibility, advancement or growth. While hygiene factors which are shown in Table 2 revolve around the structure placed on the worker by the work environment and include policies & administration, supervision-technical, relationship-superior, working conditions, salary. Other factors in each of these sets have been evaluated within the field of management science, though these five have consistently proven the most useful to applying the theory.

Table 1: Two Factor Theory Motivation Factors

Motivation factor	Definition	Related cell attributes	Related agent attributes
Achievement	Successful completion of a task, seeing results of own work, solutions to problems	`achievement-potential`	`achievement-style`
Recognition	An act of positive notice or praise	`recognition-potential`	`recognition-style`
The work itself	Positive sentiment from the actual tasks required of the job	`work-itself-potential`	`work-itself-style`
Responsibility	Responsibility over own work or that of others	`responsibility-potential`	`responsibility-style`
Advancement	Upward change in status or position	`advancement-potential`	`advancement-style`

Table 2: Two Factor Theory Motivation Factors

Hygiene factor	Definition	Related cell attributes	Related agent attributes
Policies and Administration	The organization's rules for managing the work tasks and the personnel.	`policy-style`	`policy-tolerance`
Supervision-Technical	Level of competence and fairness of the employee's supervisor.	`supervision-style`	`supervision-tolerance`
Salary	Quality of compensation.	`salary-style`	`salary-tolerance`
Interrelationships	Quality of interactions with employee's peers, subordinates, and supervisors.	`relationship-style`	`relationship-tolerance`
Working Conditions	Quality of physical conditions of the work or the facilities, and quantity of work.	`conditions-style`	`conditions-tolerance`

2 State Variables and Scales

Given the purpose of the model (see Section 1), the key elements are the work environment and the workers. The work environment is detailed in Section 2.2, which for simplicity is defined as an abstract space in which the workers make decisions about satisfaction and the work unit responds to those decisions based on certain variables, specifically these variables are identified as having variability in previous experiments within management science utilizing the Two-Factor Theory. (e.g. Hunt et al., 2012, Lundberg et al., 2009):

- Distribution of initial hygiene factors,
- Responsiveness to worker dissatisfaction,
- Responsiveness to worker satisfaction.

The workers themselves choose a work unit, based on certain variables which to influence their behavior. These variables are further explained in Section 2.3 and were specifically chosen based on experiments in the field of organizational behavior and the organizational behavior literature theories of responsiveness (e.g. Ozsoy, 2019, O'Keeffe-Foley). The worker variables are:

- Initial worker population
- Distribution of initial motivation factors
- Responsiveness to own dissatisfaction
- Responsiveness to own satisfaction
- Priority of subfactors in sequential state assessment

The relevance of both the work environment and worker variables is discussed in greater detail in Section 5.3.

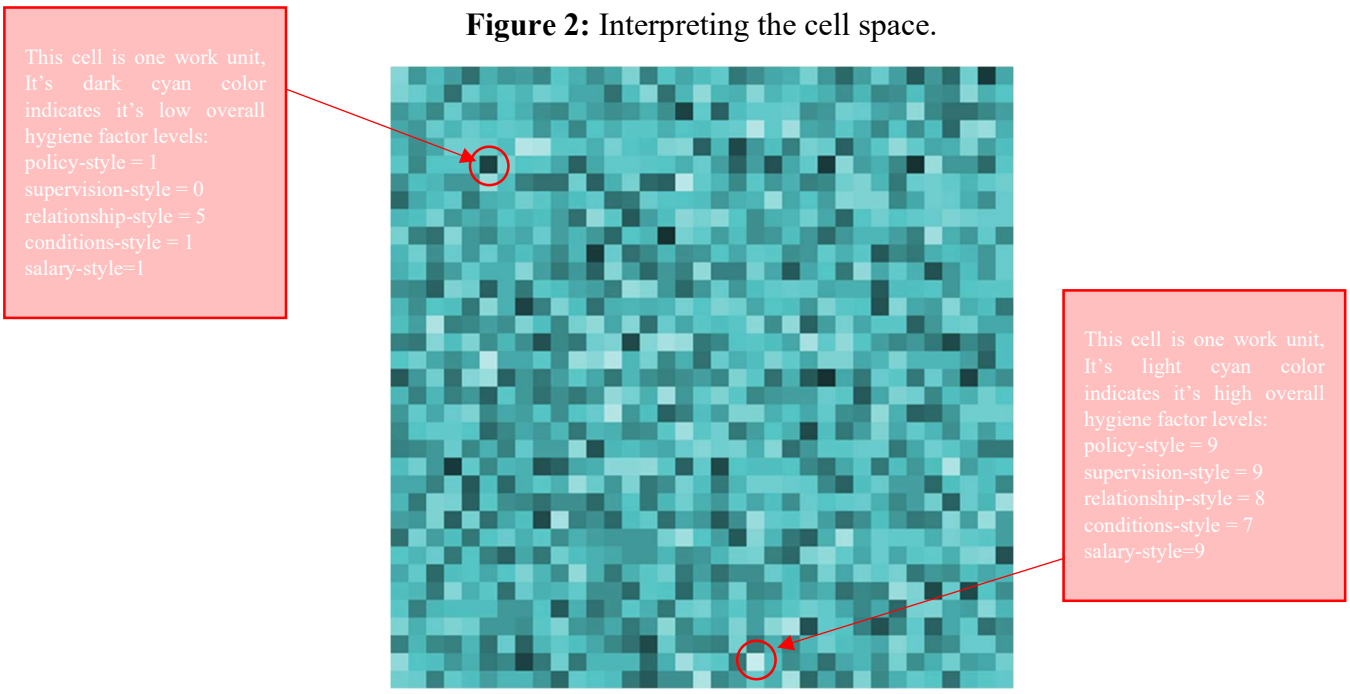
2.1 Global Variables

The model uses two global variables to determine the total number of workers with satisfaction levels that exceed dissatisfaction levels, `s-greater-d,` and the total number of workers with dissatisfaction levels that exceed their satisfaction levels, `d-greater-s`. These two global variables were chosen for validation purposes. They allow the output of the model to be compared to that found in real world data from an organization's satisfaction surveys and exit surveys. These variables are updated at the end of each time step (which is discussed more in Section 3). Additionally, a tally of new hires (`sprout-count`) and workers leaving the workforce (`die-count`) are maintained at the global level similarly to allow researchers and practitioners to compare to organizational trends in departures and hires.

2.2 The Work Environment

The work environment is a torus-shaped, 35 x 35 cell space. Each cell represents a work unit. The color of the cell is based on the total hygiene level of the work unit at the beginning of the time step. Darker cyan indicate low hygiene, while lighter cyan indicates better hygiene examples of which are shown in Figure 2. Total hygiene is effectively the sum of the five hygiene factors. To account for the ability of the factors to become negative, it is in reality the square root of the sum of the five factors squared.

Figure 2: Interpreting the cell space.



Each work unit owns a value representing each of the 5 hygiene factors and a value representing the potential level for each of the 5 motivation factors for a worker to reach in that work unit. The hygiene factor attributes are initiated based on the distribution of hygiene factors variable. The possible distributions are random, normal, or Poisson. These allow the user to account for fields that are relatively uniform in their distribution, those that have a majority of work units centered around an average, and those that have only very few with high quality work environments and the majority with low quality work environments. Table 2 is a description of each of the five hygiene factors.

As real work units have the ability to adjust their hygiene factors based on the satisfaction and dissatisfaction of the workers present (e.g., providing telework options to improve work conditions, creating job performance awards, providing profit-sharing opportunities to employees), the simulated work units have two variables, `satisfaction-turtles-here` and `dissatisfaction-turtles-here`, these relate to the average of the satisfaction and dissatisfaction of the worker present. As such, if the average satisfaction is greater than average dissatisfaction, the potential motivator factors adjust. If the converse is true, the hygiene factors adjust. If the parameters for consistent change are set to 0, no change occurs. If they are set for above or below zero, that level of change occurs to each of the related factors.

2.3 The Workers

The workers are initialized with heterogenous minimum motivation factor levels and hygiene tolerance levels. Empirical industrial organizational studies have shown that employees have different orientations with respect to the factors (Vansteenkiste et al 2007). This allows workers to weigh their satisfaction and dissatisfaction and make choices about whether to move to a new work unit. The distribution of these factors at initialization is determined by the `motivation-factor-distribution` variable which allows for uniformly, normally, or Poisson distributed factor levels. This allows the user to experiment to test the application of different theories of motivational tendencies. (Some examples of possible elements

that could be tested with minor adjustments to the model: McClelland's Motivation Theory for achievement, power, and affiliation seeking (1961, 1975) or Adam's Equity Theory (1975).) The workers also have satisfaction and dissatisfaction variables which are dependents on the difference between the worker's own minimum factor requirements and the work unit's factors in which there are present.

We assume that in the real world context the number of times a worker is able to leave an intolerable job situation in a given amount of time is limited. As such, the workers have a maximum of two work unit moves, first on whether the initial work unit meets the worker's minimum hygiene tolerance. If it does not, the worker moves to a new work unit and gets one more chance to move after assessing the minimum motivation factors. If the work unit hygiene does meet the worker's minimum standards, then they assess whether the work unit meets their minimum motivation factor requirements. If it does not meet minimum motivation requirements, the worker moves, but is then required to stay at the arrived work unit until the end of the time step. The order of this decision-making process is detailed in Section 3.

Once a worker is at a work unit that meet's their minimum motivation requirements and hygiene tolerance or the worker has exhausted their available moves for a specific time step, it then assess it's satisfaction and dissatisfaction levels. The satisfaction and dissatisfaction variables are reset if the agent moves work units. These variables are calibrated based on the original weights of each factor towards satisfaction and dissatisfaction as observed in Herzberg et al. (1959). If dissatisfaction rises to a level of beyond 100, the agent leaves the cell space to replicate leaving the work force entirely.

The complexity of the factors in the real world is importantly subjected to the context of their satisfaction and dissatisfaction in the work unit. Once their satisfaction or dissatisfaction increases, this changes their perception of what is required to motivate them. For example, if a worker receives a salary increase or significant recognition for a recently successful project, their motivation requirement and hygiene tolerances now adjust to take in this new reality. According to psychology theorists, this adjustment is a Bayesian process that people undertake in the real world (e.g. Dweck 2017) As such, the model replicates this in the abstract by adjusting the motivation levels and hygiene levels of the worker agents based on their experience in that time step. If the model parameters for consistent change are 0, no adjustment occurs. If the model parameters are set above or below 0, the motivation styles and hygiene tolerance of the agent's adjusts by that amount. Further details on this process are in Section 3.

3 Process Overview and Scheduling

Within the model, time steps are in essence abstract (notional) but could be considered to correspond to the time period between job offers provided to candidates and job acceptance/turn down from candidates. In general, this averages to a two week period, though this varies for different fields. For the purposes of this document, each time step may be considered two weeks. Workers are instantiated to a random work unit and engage in a series of decisions about their own satisfaction and dissatisfaction with the work unit. Figure 3 is a high level depiction of that process.

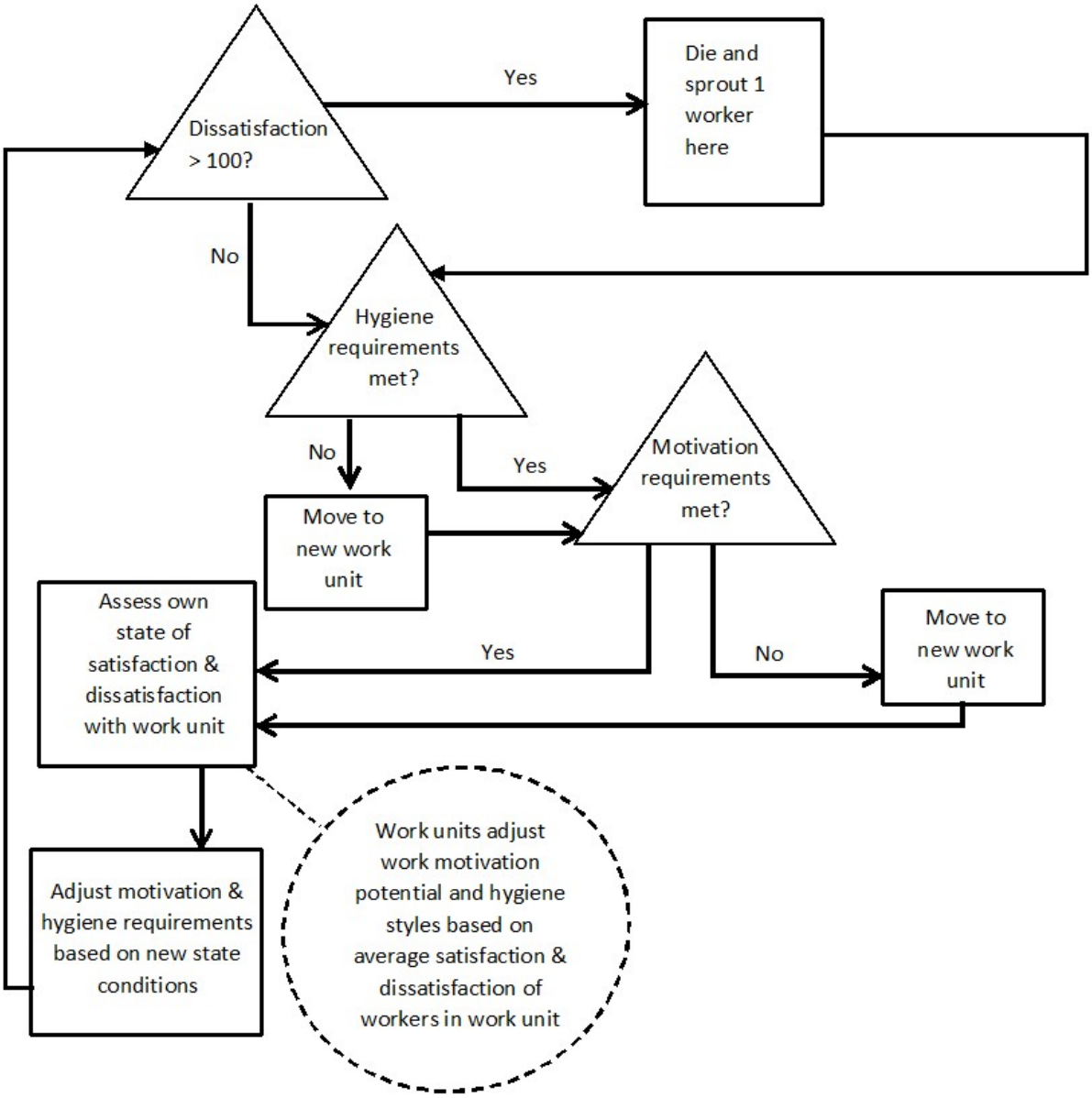


Figure 3: Agent decision tree.

4 Design Scheduling

The ODD+D protocol requires a series of design considerations be discussed, these are presented in Table 4.

Table 4: Design features

Feature	Utilization
Emergence	Given that the workers are only determining their own satisfaction and dissatisfaction with a single work unit randomly assigned, the pattern of worker convergence on a small set of work units is an emergent outcome.
Adaptation	Adaptation occurs when the workers' own factor requirements change in response to their satisfaction and dissatisfaction with their environment. Additionally, the work units themselves adapt based on the average level of worker satisfaction or dissatisfaction within their work unit.
Fitness	The fitness assessment of each worker is their primary function within the model. While this assessment is cumulative within a worker's time within a single work-unit, future iterations of the model could explore the addition of memories of previous work units.
Prediction	The adaptation that the work units undergo based on their workers present is an example of the work units predicting how best to accommodate their workers. These predictions are based on the assumptions set by the user in the parameter settings. Future iterations of this model could explicitly adjust work unit behavior to attract workers rather than only keep existing workers.
Sensing	Workers can sense the variance in their motivation requirements and hygiene tolerances and that of the potential and style of their work unit.
Interaction	The workers directly interact with their work units in their own satisfaction/dissatisfaction assessments. They indirectly interact with their fellow work unit workers through the derivation of the work unit's adaptation from the average of all the work unit's workers.
Stochasticity	Multiple sub-models rely on stochastic processes, including worker decisions to move or not, worker expectation adjustments, work unit practices adjustments. These are detailed further in Section 5.3.
Collectives	Collectives emerge as workers converge on particular work units.
Observation	The model collects data on the number of workers whose satisfaction is greater than their dissatisfaction and the converse, the number of hires and retires, the number of workers who move in a timestep. Status of the full workforce is collected at the 100, 500, 1000, 2000, and 4000th time step.

5 Details

5.1 Initialization

The first step in the initiation process is to build the work units in the cell space based on the distribution settings as described in Section 2.2. The second step is to create the initial workers based on the distribution settings and worker populations as described in Section 2.3. Once instantiated, the workers engage in a sequential "fast and frugal" decision making process of assessing their own status in the work unit as overviewed in Section 4 and detailed further in Section 5.3.

5.2 Input Data

As this is a stylized model, the model does not currently rely on input files. However, future iterations could allow users to input data based on real world experimentation. For example, employee survey data could be used to calibrate the model to that organization's specific known parameters and then the

simulation results used to identify known friction points and specific work unit concerns to either focus on from a HRM perspective or experiment with from a researcher's perspective.

5.3 Sub-models

The model proceeds as overviewed in Section 4. Within that model overview, there are six sub-models (procedures) carried out in the following order: `hire, assess-hygiene, assess-motivation, assess-state, adjust-state, and adjust-hygiene.` The former three sub-models are worker processes; the latter is a work unit process.

5.3.1 Agent Process: Hire (Die/Sprout)

At the beginning of each time step, the agent assesses whether its own dissatisfaction level is above 100. If it is, the agent dies to replicate retiring or otherwise moving on from the work force. A new worker is created on that same patch and is initialized with the same probability of attributes as the workers initialized at the start of the simulation.

5.3.2 Agent Process: Assess-hygiene (Hygiene requirements met?)

The user sets the parameter for the style of hygiene assessment the agents undertake. In the "low-satisficing" condition, the agents determine if *any one* of their minimum hygiene requirements are met within their current work unit. In the "mid-satisficing" condition, the agents determine if their `policy-tolerance` *plus* any of the other four hygiene tolerances are met. In the "high" condition, the agents determine if *all* of their hygiene requirements are met.

5.3.3 Agent Process: Assess-motivation (Motivation requirements met?)

The user sets the parameter for the style of motivation assessment the agents undertake. In the "short-term" condition, the agents determine if their factors related to short-term satisfaction (achievement and recognition) are met. In the "long-term" condition, the agents determine if their factors related to long-term satisfaction (work itself, responsibility, and advancement) are met. In the "half-short-long" condition, the half of the agents are designated as assessing short term factors and half are designated as assessing long term factors. This agent attribute is created at initialization of the worker and does not change through the life of that worker in the simulation. However, the attribute is only accessed in this specific condition of the model. In the "varied" condition, a fifth of the agents are designated as assessing one of each of the motivating factors. This designation is also created at the initialization of the worker and remains for their life in the simulation, accessed only in this condition.

5.3.4 Agent Process: Assess-state

The worker agent sequentially assesses its own minimum motivation preferences and hygiene tolerances in relation to the motivation potential and hygiene style of its work unit. It derives its satisfaction and dissatisfaction state using the weights originally presented in Herzberg et al. (1959) for the level of contribution found for each of the factors. The contribution of each of these calculations is detailed in Table 5.

Table 5: Assess-state calculations[1]

Agent variable	Cell variable	If agent variable < cell variable, agent **satisfaction** increases by:	If agent variable < cell variable, agent **dissatisfaction** increases by:
achievement-style	achievement-potential	0.2	
recognition-style	recognition-potential	0.17	
work-itself-style	work-itself-potential	0.13	
responsibility-style	responsibility-potential	0.12	
advancement-style	advancement-potential	0.10	
policy-tolerance	policy-style		0.28
supervision-tolerance	supervision-style		0.18
salary-tolerance	salary-style		0.15
relationship-tolerance	relationship-style		0.14
conditions-tolerance	conditions-style		0.10

5.3.5 Agent Process: Adjust-state

The user sets the parameters for how the agents adjust their motivation and hygiene requirements, given their current satisfaction and dissatisfaction levels. In the "consistent change" condition, if the amount of change is set to "0" the adjust-state process effectively doesn't occur. If it is set to greater or less than "0," the process occurs as follows: if the worker's satisfaction level is greater than it's dissatisfaction level, the motivation factor attributes change based on the `motivation-consistent-change-amount`. Conversely, if the worker's dissatisfaction level is greater than its satisfaction level, the hygiene factor attributes are change based on the `tolerance-consistent-change-amount`.

It should also be noted that two other conditions are also possible here, for researchers who want to simulate variable workforce reactions. In the "varied increase" condition, the increase for each of the motivation and/or hygiene requirements varies based on the distribution (random, normal, Poisson) set by the user. Conversely, the same applies in the "varied decrease" condition.

5.3.6 Cell process: Adjust-hygiene

Each work unit calculates the average satisfaction and dissatisfaction level of the workers on its cell. Then, based on parameters set by the user for how the work units adjust their motivation potential and

[1] Motivation factors only contributes to satisfaction, not dissatisfaction and Hygiene factors only contribute to dissatisfaction, not satisfaction. As such, the cells representing portions where a factor is not applied to a score have been greyed out.

hygiene style, the work units attributes adjusts. In the "consistent change" condition, if the amount of change is set to "0" the adjust-hygiene process effectively doesn't occur. If it is set to greater or less than "0," the process occurs as follows: If the average worker satisfaction level is greater than the average worker dissatisfaction level, the motivation-related attributes change based on the `potential-consistent-change-amount`. Conversely, if the average worker dissatisfaction level is greater than the average worker satisfaction level, the hygiene factor attributes are change based on the `hygiene-consistent-change-amount`.

As with the agent process in Section 5.3.5, two other conditions are also possible here, for researchers who want to simulate variable workforce reactions. In the "varied increase" condition, the increase for each of the motivation and/or hygiene attributes for the work unit varies based on the distribution (random, normal, Poisson) set by the user. Conversely, the same applies in the "varied decrease" condition.

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