Axial potential distribution as a Schrödinger potential: a wave model of flow control in socio-technological systems

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Sergey V. Kibalnikov[1] *(corresponding author, kibalnikov@gmail.com)*, [co-authors]

[1] Dubna State University, Dubna, Russia; LLC «Izobretatel», Moscow, Russia

Abstract. Ginzburg and Kibalnikov (2011) transferred two design notions of high-efficiency electron-vacuum devices — perveance and the axial potential distribution (APD, Russian ОРП) — to the management of socio-technological systems (STS), but left them without a dynamical equation. We close this gap. Using the Picht transformation, we show that the paraxial trajectory equation governed by an APD υ(s) is exactly a stationary Schrödinger-type equation with an effective potential fixed by the shape of υ(s). Adding the self-field of the flow yields a Schrödinger–Poisson system in which the generalized perveance K enters as the coefficient of a cubic nonlinearity, while the flow emittance ε plays the role of Planck's constant, as in the thermal-wave model of charged-particle beams. Mapped onto an STS — a staged cycle of cognition, learning, management and production — the model gives four testable results: (i) a matched-flow condition linking incentive design, load and heterogeneity; (ii) a Floquet stability bound on the rhythm of periodic control points (phase advance per period below 180°, below 90° under heavy load); (iii) an identification of the standing-wave regime with zero net throughput, i.e. the social analogue of a virtual cathode; (iv) a WKB estimate of how far a flow can cross a motivational gap. We give an estimation protocol from stage-wise pipeline data and four falsifiable hypotheses. The model is a classical wave description of flow distributions and makes no claim of quantum effects in society.

Keywords: perveance; axial potential distribution; Schrödinger equation; thermal-wave model; Child–Langmuir law; socio-technological systems; flow control; Floquet stability

1. Introduction

Managing a socio-technological system (STS) means steering flows — of people, projects, goods, money or knowledge — through a sequence of stages without either starving them or overloading them to collapse. Statistical physics has supplied many models of such flows: kinetic and fluid models of traffic [1, 2], social-force models of crowds [3], and opinion dynamics [4]. Quantum-like models of cognition, finance and social decision-making form a second, more recent line [5–7]. What both lines largely lack is a *design* theory: given a desired flow, how should the external field acting on it be shaped?

Electron optics solved exactly this design problem for intense beams. In high-power vacuum devices the external field is specified by the axial potential distribution (APD) along the beam axis, and the intensity of the beam relative to its accelerating voltage is measured by the perveance $P = I/U^{3/2}$, a similarity criterion that fixes the geometry of the gun [8, 9]. Ginzburg and Kibalnikov [10] used this methodology — which produced klystrons and titrons with efficiencies up to 76% [10, 11] — to propose a *social perveance* and a *social APD* as control variables of an STS, modelled as a Kron-type generalized machine with input power N, losses G and useful power P [12]. The proposal was conceptual: it named the variables and the target regime ($P \approx 0.5$ μA/V$^{3/2}$) but gave no equation of motion for the flow under a given APD.

This paper supplies that equation. Our starting point is a classical fact that is rarely used outside accelerator physics: the paraxial equation of electron optics can be rewritten, by the Picht transformation [13], as a stationary Schrödinger-type equation, and the transport of a beam with finite emittance obeys a Schrödinger-like equation in which emittance replaces $\hbar$ — the thermal-wave model [14]. The wave formalism therefore follows from optics and mechanics alone; no quantum hypothesis about society is needed.

The contributions are:

1. A model chain from APD to observables: $u(s) \to$ effective focusing $\kappa(s) \to$ Schrödinger–Poisson system with perveance as nonlinearity and emittance as effective Planck constant (Section 3).
2. Five propositions that turn known beam-physics results into management statements: matched flow, rhythm stability, standing wave as zero throughput, tunnelling through motivational gaps and energy recuperation (Section 4).
3. An estimation protocol from stage-wise pipeline data and four falsifiable hypotheses (Section 5).

We also correct a point left open in [10]: the APD is not a standing wave. It is a static profile that a moving flow experiences as a rhythm, whereas a genuine standing wave of the flow carries zero current and marks a failure regime.

2. Background

2.1 Perveance and the space-charge limit

For a planar diode with gap d and voltage U, the Child–Langmuir law gives the maximum current density that the field can draw against the repulsion of the beam's own space charge [15, 16]:

$$J_{CL} = \frac{4\varepsilon_0}{9}\sqrt{\frac{2q}{m}}\;\frac{U^{3/2}}{d^2}$$

The ratio P = I/U^{3/2} is therefore a geometric invariant of the gun: once electrode shapes are fixed, P does not depend on the operating voltage [8]. In the LT dimensional system of Bartini and Kuznetsov, P has dimension $[L^0T^0]$ — it is a pure similarity number [10, 27, 28]. For transport after the gun, the relevant quantity is the generalized perveance; in the non-relativistic case

$$K = \frac{qI}{2\pi\varepsilon_0 m v^3} = \frac{qI}{2\pi\varepsilon_0 m}\left(\frac{m}{2qU}\right)^{3/2} \;\propto\; \frac{I}{U^{3/2}} = P$$

so K measures how strongly a beam of given current pushes itself apart at a given potential [9, 17].

2.2 Axial potential distribution

An electrostatic focusing system is fully described by u(s), the potential on the axis as a function of the longitudinal coordinate s; the off-axis field follows by analytic continuation of the Laplace equation [10, 18]. Ginzburg and Kibalnikov [10] split the total potential into an external part u_1, encoded by the APD, and the self-field u_2 of the space charge, and solved the problem self-consistently cross-section by cross-section. Alternating regions with $u'' > 0$ and $u'' < 0$ act as converging and diverging lenses; a titron gun uses two lenses, the titron "bell" four [10]. Recuperation — lowering the potential at the end of the flight to return the spent beam's energy to the supply — doubled klystron efficiency in practice [10, 29].

2.3 The social generalized machine

Following Kron [12], a generalized machine is a channel that carries a power flow N from a source to a load, losing G and delivering P = N − G. The *social* generalized machine of [10] is a network of such machines embedded in a society and cycling through four processes: cognition → learning → management → production. The authors proposed that a healthy STS has a characteristic social perveance, that crises correspond to the virtual-cathode regime of an over-perveant beam, and that APD design is the lever of management. Section 3 gives these statements a dynamical form.

3. Model

3.1 Coordinates

Let s ∈ [0, L] be progress along the STS cycle (cognition → learning → management → production), measured in stage units. Let ξ be the transverse deviation of a flow element — a participant, project or unit of capital — from the reference trajectory, i.e. from full alignment with the cycle's goal, and ξ′ = dξ/ds its rate of divergence. Following [10] we take the potential as the square of the flow velocity, υ = v², so υ(s) is the APD designed by management (incentives, gates, resources) and v(s) the resulting speed of passage through stage s. I is the throughput (elements per unit time).

3.2 APD as an effective Schrödinger potential

The paraxial trajectory equation of electrostatic optics is [8, 18]

$$\xi'' + \frac{\upsilon'}{2\upsilon}\,\xi' + \frac{\upsilon''}{4\upsilon}\,\xi = 0 \tag{1}$$

The Picht substitution R = ξ·υ^{1/4} removes the first-derivative term [13]:

$$R'' + T(s)\,R = 0, \qquad T(s) = \frac{3}{16}\left(\frac{\upsilon'(s)}{\upsilon(s)}\right)^{2} \tag{2}$$

Equation (2) is the stationary Schrödinger equation ψ″ + (2m/ħ²)(E − V)ψ = 0 with s as coordinate, R as wave function and T(s) in place of (2m/ħ²)(E − V). The *shape* of the APD alone — through the logarithmic derivative υ′/υ — fixes the effective potential. Two consequences follow at once: T ⩾ 0, so a pure external APD always focuses on balance (the analogue of Scherzer's theorem [18]); and a constant υ gives T = 0, i.e. a flat incentive profile exerts no steering at all, however high it is.

3.3 Envelope equation with self-field and heterogeneity

A real flow has a self-field (mutual repulsion of its elements: competition for the same resources, congestion, conflict) and a finite spread in (ξ, ξ′), its emittance ε. For a uniform-density flow the root-mean-square envelope a(s) obeys the Kapchinskij–Vladimirskij equation [17, 9], written in Picht-reduced variables:

$$a'' + T(s)\,a - \frac{K}{a} - \frac{\varepsilon^{2}}{a^{3}} = 0 \tag{3}$$

The three terms compete: T(s) is the steering imposed by the APD; K/a is the self-repulsion, proportional to perveance; ε²/a³ is the pressure of the flow's own heterogeneity.

3.4 Wave formulation: a Schrödinger–Poisson system

Fedele and Miele [14] showed that transverse beam transport is described by a Schrödinger-like equation in which the emittance ε plays the role of ħ and $|\psi(\xi, s)|^2$ is the transverse density; the second moment of $|\psi|^2$ then reproduces the envelope equation (3). Including the self-field Φ gives the system

$$i\varepsilon\,\frac{\partial \psi}{\partial s} = -\frac{\varepsilon^{2}}{2}\,\frac{\partial^{2}\psi}{\partial \xi^{2}} + \left[\tfrac{1}{2}\,T(s)\,\xi^{2} + \Phi(\xi,s)\right]\psi, \qquad \frac{\partial^{2}\Phi}{\partial \xi^{2}} = -K\,|\psi|^{2} \tag{4}$$

This is precisely the self-consistent split of [10]: T(s) comes from the external APD u_1, Φ is the self-field u_2, and each step in s recomputes Φ from the current density — the Hartree scheme. In the local limit $\Phi \approx gK|\psi|^2$ system (4) reduces to a Gross–Pitaevskii equation [22, 23] whose cubic coefficient is proportional to perveance.

Along the axis, passage through the cycle is governed by the longitudinal counterpart of (2),

$$\varphi'' + k^{2}(s)\,\varphi = 0, \qquad k(s) = \frac{\sqrt{2\,u(s)}}{\varepsilon_{L}}, \qquad j = \varepsilon_{L}\,\mathrm{Im}\!\left(\varphi^{*}\varphi'\right) \tag{5}$$

with ε_L the longitudinal emittance (spread of passage speeds) and j the net flow, which corresponds to throughput I.

3.5 Correspondence

Symbol	Electron beam	STS	Proxy for estimation
s	Axial coordinate	Progress along the cycle	Stage index
u(s)	Axial potential (APD)	Designed incentive profile	v^2, from stage passage speed
T(s)	Effective focusing	Steering by the APD	$(3/16)(u'/u)^2$
ξ, ξ′	Transverse position, angle	Deviation from goal, its drift	Alignment score, its change per stage
ε	Emittance (effective ħ)	Irreducible heterogeneity of the flow	Area of the (ξ, ξ′) cloud
K	Generalized perveance	Self-repulsion under load	I / u^{3/2}, scaled

Symbol	Electron beam	STS	Proxy for estimation
$\|\psi\|^2$	Transverse density	Distribution of elements across states	Cohort histogram per stage
j	Beam current	Net throughput	Completions per unit time

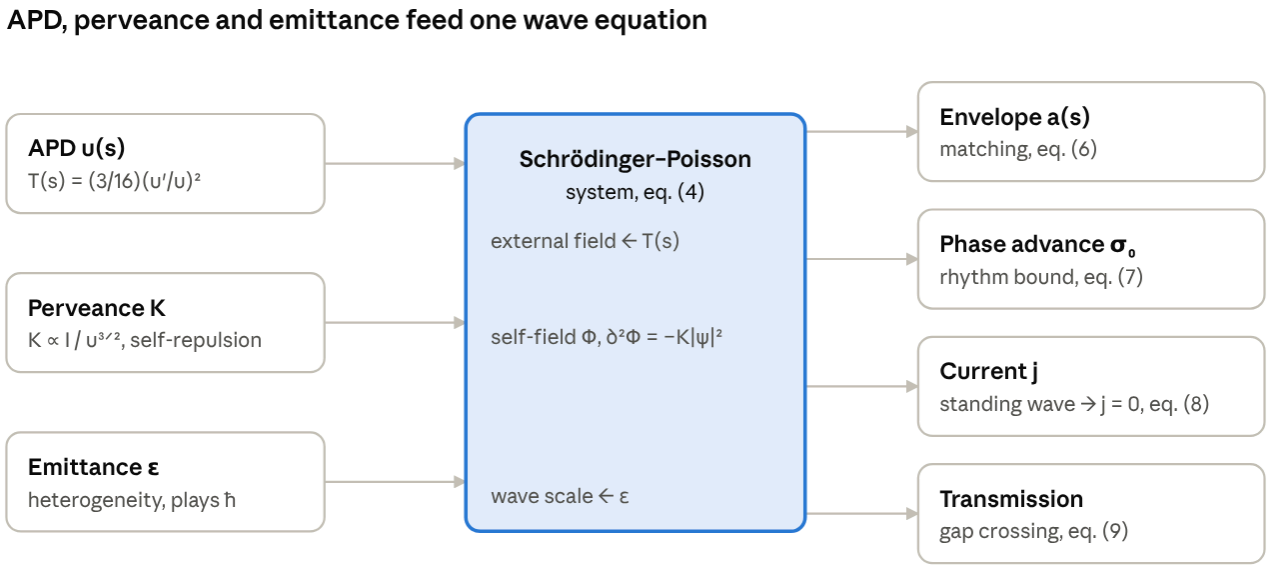


Figure 1. Model chain: design inputs, wave equation, observables

Figure 1. The APD enters only through its logarithmic derivative, perveance sets the strength of the self-field, and emittance sets the wave scale; the four observables on the right are the subjects of Propositions 1–4.

4. Results

The propositions below are known results of beam physics restated for the model of Section 3; their content for STS lies in the interpretation and in the quantities that become measurable.

Proposition 1 (matched flow). For a constant focusing strength $T = k_0^2$, equation (3) has a stationary (matched) envelope a_0 given by

$$k_0^{2}\,a_0 - \frac{K}{a_0} - \frac{\varepsilon^{2}}{a_0^{3}} = 0, \qquad \eta = \frac{k}{k_0} = \sqrt{1 - \frac{K}{k_0^{2}a_0^{2}}} \in (0, 1] \tag{6}$$

where η is the space-charge depression. As η → 1 the flow is heterogeneity-dominated (the APD steers a light load); as η → 0 it is load-dominated and the APD only just contains self-repulsion. Both limits are failure modes. The fixed target P ≈ 0.5 μA/V^{3/2} proposed in [10] is specific to electron guns; the dimensionless invariant that transfers to an STS is

η, and the operating band for η must be estimated from data (Section 5). Equation (6) also states the design rule directly: for a given load K and heterogeneity ε, the APD must supply $k_0^2 = K/a_0^2 + \varepsilon^2/a_0^4$.

Proposition 2 (rhythm of control points). Let the APD be periodic with period λ — regular reviews, sprints or round tables — so that T(s + λ) = T(s). Equation (2) becomes a Hill equation, and by Floquet theory [19] trajectories are bounded only if the zero-load phase advance per period satisfies $\sigma_0 < 180°$. With strong space charge, envelope instabilities appear already for $\sigma_0 > 90°$ [21]. For slowly varying T the phase advance is $\sigma_0 \approx \int_0^\lambda \sqrt{T}\, ds$, which with (2) gives

$$\sigma_0 \approx \frac{\sqrt{3}}{4}\int_0^{\lambda}\left|\frac{d\ln u}{ds}\right| ds \tag{7}$$

The stability bound is therefore a bound on the total logarithmic swing of incentives within one review period: under heavy load, $\sigma_0 < 90°$ requires a total log-variation below $(4/\sqrt{3})\cdot(\pi/2) \approx 3.6$, i.e. a peak-to-trough incentive ratio below about $e^{1.8} \approx 6$ for one swing up and down; under light load the bound is about twice as wide in log terms. Equation (7) relies on a WKB approximation and should be checked numerically for sharp profiles. The band structure of a periodic APD (Bloch [20]) adds a second statement: flows whose wave number satisfies $k\lambda \approx n\pi$ are reflected even when the potential suffices.

Proposition 3 (standing wave means zero throughput). By (5), j is constant along s. Writing $\varphi = A e^{iks} + B e^{-iks}$ gives

$$j = \varepsilon_L\,k\left(|A|^{2} - |B|^{2}\right) \tag{8}$$

A standing wave ($|B| = |A|$, φ real up to a phase) carries j = 0: the flow is fully reflected at a turning point where $u(s) \to 0$. This is the virtual cathode of [10] in wave language. The APD itself is static in the frame of the institution; an element moving at speed v experiences its spatial period λ as a temporal rhythm $\omega = 2\pi v/\lambda$. The APD is therefore *not* a standing wave; a standing wave of the flow is the failure the APD must prevent.

Proposition 4 (crossing a motivational gap). Where the net potential is negative on $[s_1, s_2]$ — funding stops, rewards vanish — the WKB transmission of (5) is

$$\mathcal{T} \approx \exp\!\left(-\frac{2}{\varepsilon_L}\int_{s_1}^{s_2}\sqrt{2\,|u(s)|}\;ds\right) \tag{9}$$

Transmission falls exponentially with gap length times the square root of its depth, and rises with longitudinal heterogeneity ε_L: flows with a wider spread of speeds cross gaps more easily. Splitting one wide gap into two narrow ones separated by a short supportive

interval can produce resonant transmission close to unity when the interval length matches a standing mode — a sharp, testable design prediction.

Proposition 5 (recuperation). With input power N, useful power P and losses G (N = P + G), recovering a fraction r of the spent flow's energy at the collector — depressed-collector operation [29] — raises efficiency to

$$\eta_{eff} = \frac{P}{N - rG} \tag{10}$$

without any increase in throughput. In an STS this corresponds to returning the residue of a completed cycle — experience, unused resources, intellectual property — to the start of the next one.

5. Operationalization

Every quantity in (3)–(9) can be estimated from stage-wise event logs: entry and exit timestamps per element per stage, plus a per-stage state score (goal alignment, competence or a coherence index). Such logs exist in project pipelines, degree programmes, cooperative ledgers and grant systems.

5.1 Estimators

1. **Velocity and APD.** By Little's law [25], the mean passage speed through stage s is $v_s = \ell_s / W_s$, where ℓ_s is stage length (one unit) and W_s the mean sojourn time; then $u(s) = v_s^2$, interpolated to a smooth profile, and T(s) follows from (2).
2. **Throughput and perveance.** I is completions per unit time; $K = c \cdot I/u^{3/2}$, with the scale c fitted in step 4.
3. **Heterogeneity.** With ξ the deviation of an element's state score from the cohort target and ξ′ its change per stage, the rms emittance is

$$\varepsilon = \sqrt{\langle \xi^{2}\rangle\langle \xi'^{2}\rangle - \langle \xi\,\xi'\rangle^{2}} \tag{11}$$

The longitudinal emittance ε_L is computed the same way from the spread of entry times and passage speeds.

Step 4 — fit. The observed rms width $a(s) = \langle \xi^2 \rangle^{1/2}$ per stage is fitted by (3) with c as the only free parameter; the residual is a goodness-of-fit test of the model itself.

5.2 Falsifiable hypotheses

#	Hypothesis	Test	Falsified if
H1	Capacity law: maximum sustainable throughput of a stage scales as υ^{3/2}	Log–log regression of peak throughput on υ across stages and organisations	Slope's 95% CI excludes 1.5
H2	Matching: completion rate peaks in an interior band of η and falls at both ends	Completion rate against η from (6), with controls	Monotone relationship, or no interior maximum
H3	Rhythm: incentive log-swing per review period above the bound (7) predicts growth of a(s) and drop-out	Compare periods above and below the bound; A/B variation of review period λ	No difference in envelope growth or drop-out
H4	Gap crossing: survival through a resource gap decays as exp(−length·√depth / ε_L)	Survival analysis over funding or reward interruptions	Decay not exponential in length·√depth, or no dependence on ε_L

5.3 Pilot design

We propose a pre-registered pilot in a cooperative research and education network with blockchain-timestamped event logs, so that stage entries and exits are tamper-evident. Two cohorts run the same four-stage cycle; the review period λ is varied between them (H3), and planned resource gaps of different lengths are introduced where ethically acceptable (H4). Sample size is set by a power analysis on the variance of a(s) observed in a first calibration cycle. No results are reported here; the pilot is the subject of a follow-up paper.

5.4 Case designs: a university programme and an industrial plant

The same protocol applies to two contrasting STS. If the H1 slope and the operating band of η coincide across them, perveance behaves as an invariant of STS rather than as a metaphor; if they differ, the model still supplies comparable parameters.

Case A — university or continuing-education programme. The flow is students; stages are modules or terms; the event log is the learning-management system and grade records. Throughput I is module completions per month; υ(s) = (1/mean time to pass)²; ξ is

the deviation of a student's assessed competence from the module target; K is the student-to-instructor load scaled by υ^{3/2}; λ is the spacing of control points; gaps (υ < 0) are vacations, leaves of absence and interruptions of stipends.

Hypothesis	Design	Falsifier
H1	Peak module throughput against υ^{3/2} across programmes or departments	95% CI of log–log slope excludes 1.5
H2	Groups of different size give different K; completion rate against η	No interior maximum
H3	Parallel groups with weekly, fortnightly and monthly control points and different weights of interim marks	No difference in growth of a(s) or drop-out across the bound (7)
H4	Survival analysis of return after vacations or leave, by length·√depth and by pace heterogeneity ε_L; a short mid-break summer school tests resonant transmission	No exponential dependence, or none on ε_L

Minimum pilot: two or three parallel groups of 20–30 students over one academic year, with ethics approval and informed consent; H4 uses only naturally occurring breaks.

Case B — TechnoNICOL LOGICPIR plant, Ryazan. The plant, opened in May 2016 with a design capacity of 30 million m² of polyisocyanurate insulation per year, is one of the company's production sites in Ryazan [30]. The production line itself is a physical continuous flow; the STS flows are (i) improvement proposals — idea → evaluation → approval → implementation → verified effect — and (ii) workforce development — hiring → onboarding → qualified operator → mentor. Proposal pipelines, loss analysis and lean audits supply stage-wise logs, and the company's multi-plant network allows cross-site comparison.

Hypothesis	Design	Falsifier
H1	Peak implemented proposals per month against υ^{3/2} across 10–20 plants	Slope ≠ 1.5
H2	Shop floors with different evaluator load (queue per evaluator); implementation rate against η	No interior maximum

Hypothesis	Design	Falsifier
H3	Shop floors or shifts with weekly vs fortnightly improvement committees, and fixed vs fluctuating rewards per proposal; outcomes are growth of a(s) and the share of stalled proposals	No difference
H4	Survival of proposals through planned maintenance shutdowns and the seasonal construction downturn, by gap length·√depth and flow heterogeneity; a short mid-gap kaizen session tests resonant transmission	No exponential dependence
P5	Efficiency before and after an idea bank with periodic re-review of rejected proposals	No efficiency gain at unchanged I

Minimum pilot: six to nine months including the seasonal downturn, two to four comparable shop floors for A/B designs, and a cross-plant extract for H1. The plant is a study site of the funded team research project "The TechnoNICOL phenomenon: measurable coherence of the production environment. A digital twin (IoT + AI + blockchain data verification) as a tool for studying the sources of the company's resilience". Within that project, IoT data from the line and blockchain verification of event logs supply tamper-evident stage records, and the digital twin hosts the estimators of Section 5.1.

6. Discussion and limitations

Relation to quantum-like social science. Quantum models of cognition and finance [5–7] postulate a Hilbert-space structure for beliefs or prices. Our model postulates nothing of the kind: the Schrödinger form follows from classical optics through the Picht transformation (2) and from beam transport with finite emittance [14], exactly as Schrödinger's own equation was motivated by the Hamilton optico-mechanical analogy [26]. The "Planck constant" of the model is the emittance — a measurable spread of the flow — not a fundamental constant. This makes the model closer to the kinetic and fluid models of collective motion [1–3] than to quantum cognition; the Madelung form of (4) [24] would make the link to fluid models explicit.

What the model adds. Existing flow models describe how a crowd or a traffic stream responds to a given environment. The present model inverts the question in the way electron optics did: it treats the environment — the APD — as the design variable and

gives explicit conditions on it: matching (6), rhythm (7), reflection (8), gap crossing (9) and recuperation (10).

Relation to the strategy of configuration. Jullien [32] contrasts two models of efficacy. In the European model, codified by Clausewitz [31], the strategist fixes an end, decomposes it into steps and applies force to each step; victory goes to the side with greater resources. In the Chinese model of Sun Tzu [33], efficacy comes from *shi* — the potential inherent in a disposition of things. The strategist arranges the situation so that the desired outcome comes about by itself, and avoids direct confrontation. The APD is a formal counterpart of *shi*. Management does not act on each element of the flow; it shapes the profile $u_1(s)$, and trajectories follow from it. Equation (2) makes the point quantitative: the steering $T(s)$ depends only on the shape of the profile, through u'/u, and not on its level. A uniformly high incentive (u = const) is pure Clausewitzian mass and steers nothing, whereas a modest but well-shaped profile focuses the flow.

The self-consistent term u_2 adds a second element of Jullien's account: a configuration is not imposed once but continuously adjusted to the field the flow itself creates, as water adapts to the terrain. In this reading, Propositions 1 and 2 state when a disposition is "ripe" — matched to the load and paced at a stable rhythm — and Proposition 3 describes the failure of a strategy of force: when the flow is pushed against its own space charge, it is reflected instead of carried. The analogy gives the model a conceptual lineage in strategic thought; it is not offered as evidence.

Limitations.

1. *Definition of potential.* Identifying u with v^2 follows [10] and Newtonian mechanics, but in an STS passage speed also depends on the elements' own choices; $u(s)$ estimated from speeds conflates design and response. Instrumental variation of incentives is needed to separate them.
2. *Linearity and paraxiality.* Equations (1)–(3) hold for small deviations ξ. Organisations with large internal splits fall outside the paraxial regime.
3. *Reflexivity.* Electrons do not read the design of the gun; people do. Announced changes of the APD can alter behaviour before they take effect, which the model ignores.
4. *Dimensional transfer.* The LT-dimensional argument that P is a pure number [10, 27] justifies treating perveance as a similarity invariant, but the numerical optimum of electron guns does not transfer; only dimensionless combinations such as η and σ_0 can be compared across systems.
5. *No empirical test yet.* All propositions are derived, not observed. Section 5 specifies how they can fail.

7. Conclusion

The axial potential distribution proposed by Ginzburg and Kibalnikov as a lever of STS management has a precise dynamical meaning: through the Picht transformation it is an effective Schrödinger potential, and with self-field and heterogeneity it drives a Schrödinger–Poisson system in which perveance sets the nonlinearity and emittance plays the role of ħ. The model turns three intuitions of [10] into checkable statements — that load must be matched to incentive design, that the rhythm of control points has a stability limit, and that crisis corresponds to a reflected, zero-throughput standing wave — and adds two design results on crossing resource gaps and recovering spent energy. The next step is the pre-registered pilot of Section 5.

Declarations

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References

1. Lighthill M.J., Whitham G.B. On kinematic waves II. A theory of traffic flow on long crowded roads. *Proc. R. Soc. Lond. A* 229 (1955) 317–345.
2. Helbing D. Traffic and related self-driven many-particle systems. *Rev. Mod. Phys.* 73 (2001) 1067–1141.
3. Helbing D., Molnár P. Social force model for pedestrian dynamics. *Phys. Rev. E* 51 (1995) 4282–4286.
4. Castellano C., Fortunato S., Loreto V. Statistical physics of social dynamics. *Rev. Mod. Phys.* 81 (2009) 591–646.
5. Busemeyer J.R., Bruza P.D. *Quantum Models of Cognition and Decision.* Cambridge University Press, 2012.
6. Haven E., Khrennikov A. *Quantum Social Science.* Cambridge University Press, 2013.
7. Baaquie B.E. *Quantum Finance: Path Integrals and Hamiltonians for Options and Interest Rates.* Cambridge University Press, 2004.
8. Pierce J.R. *Theory and Design of Electron Beams,* 2nd ed. Van Nostrand, 1954.

9. Reiser M. *Theory and Design of Charged Particle Beams,* 2nd ed. Wiley-VCH, 2008.
10. Ginzburg V.E., Kibalnikov S.V. A view of technological problems of sustainable development of human civilization from the position of perveance electron optics. *Sustainable Innovative Development: Design and Management* 7(4) (2011) 38–52 (in Russian).
11. Ginzburg V.E. Theory, design, creation and application features of transit titron electron-vacuum devices. Doctoral dissertation, VEI, Moscow, 1987 (in Russian).
12. Kron G. *Tensor Analysis of Networks.* Wiley, 1939.
13. Picht J. Beiträge zur Theorie der geometrischen Elektronenoptik. *Annalen der Physik* 407 (1932) 926–964.
14. Fedele R., Miele G. A thermal-wave model for relativistic-charged-particle beam propagation. *Il Nuovo Cimento D* 13 (1991) 1527–1544.
15. Child C.D. Discharge from hot CaO. *Phys. Rev. (Series I)* 32 (1911) 492–511.
16. Langmuir I. The effect of space charge and residual gases on thermionic currents in high vacuum. *Phys. Rev.* 2 (1913) 450–486.
17. Kapchinskij I.M., Vladimirskij V.V. Limitations of proton beam current in a strong focusing linear accelerator associated with the beam space charge. *Proc. Int. Conf. on High-Energy Accelerators and Instrumentation,* CERN, Geneva, 1959, 274–288.
18. Hawkes P.W., Kasper E. *Principles of Electron Optics,* Vol. 1. Academic Press, 1989.
19. Floquet G. Sur les équations différentielles linéaires à coefficients périodiques. *Ann. Sci. École Norm. Sup.* 12 (1883) 47–88.
20. Bloch F. Über die Quantenmechanik der Elektronen in Kristallgittern. *Z. Physik* 52 (1929) 555–600.
21. Hofmann I., Laslett L.J., Smith L., Haber I. Stability of the Kapchinskij–Vladimirskij (K–V) distribution in long periodic transport systems. *Particle Accelerators* 13 (1983) 145–178.
22. Gross E.P. Structure of a quantized vortex in boson systems. *Il Nuovo Cimento* 20 (1961) 454–477.
23. Pitaevskii L.P. Vortex lines in an imperfect Bose gas. *Sov. Phys. JETP* 13 (1961) 451–454.
24. Madelung E. Quantentheorie in hydrodynamischer Form. *Z. Physik* 40 (1927) 322–326.
25. Little J.D.C. A proof for the queuing formula L = λW. *Operations Research* 9 (1961) 383–387.
26. Schrödinger E. An undulatory theory of the mechanics of atoms and molecules. *Phys. Rev.* 28 (1926) 1049–1070.
27. Bartini R.O. Some relations between physical constants. *Doklady Akademii Nauk SSSR* 163(4) (1965) 861–864 (in Russian).

28. Kuznetsov O.L., Kuznetsov P.G., Bolshakov B.E. *Nature–Society–Man System: Sustainable Development.* Noosfera, Moscow–Dubna, 2000 (in Russian).
29. Kosmahl H.G. Modern multistage depressed collectors — a review. *Proc. IEEE* 70(11) (1982) 1325–1334.
30. TechnoNICOL. TechnoNICOL launched production of innovative LOGICPIR insulation in Ryazan. Company press release, 24 May 2016. https://technonicol.com/about/press/news/technonicol_launched_production_of_innovative/
31. Clausewitz C. von. *Vom Kriege.* Dümmlers Verlag, Berlin, 1832. English translation: *On War,* ed. and transl. M. Howard and P. Paret. Princeton University Press, 1976.
32. Jullien F. *Traité de l'efficacité.* Grasset, Paris, 1996. English translation: *A Treatise on Efficacy: Between Western and Chinese Thinking.* University of Hawai'i Press, 2004.
33. Sun Tzu. *The Art of War,* transl. S.B. Griffith. Oxford University Press, 1963.